Corrosion

OFFICIAL PUBLICATION
NATIONAL ASSOCIATION
of
CORROSION ENGINEERS

OCTOBER
1960

Vol. 16 No. 10

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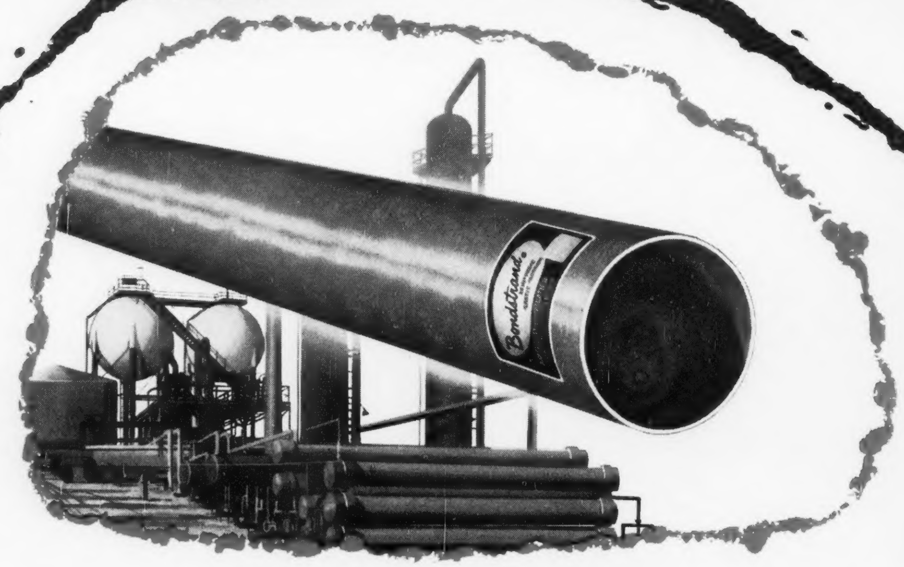

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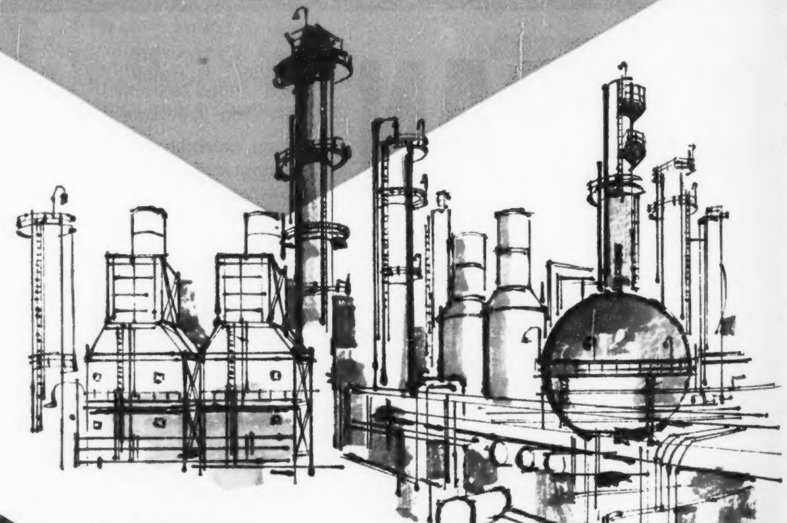

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This Month in Corrosion Control . . .

UNDERGROUND EQUIPMENT at gasoline service stations can and should be protected against corrosion damage. Useful economic and cathodic protection design information is given in an article beginning on Page 9.

ELECTROLYSIS SWITCHES used to drain stray currents from telephone cables to traction system negative bus are damaged when power to the traction system is suddenly interrupted. Germanium diodes connected across the coil and the series resistance for a half volt scale on the meter will prevent this damage. Turn to Page 16.

CHEMICAL CLEANING, using inhibited hydrochloric acid, should be done by professional-type contract rather than on a low bid basis because of the safety and corrosion hazards inherent in the method. See an exposition of this problem from the contractor's viewpoint, beginning on Page 18.

COAL BURNING PISTON ENGINES suffer from contamination of the lubricating oil by coal dust, tests reported in an article beginning on Page 28 show.

COOLING WATERS IN CITIES pick up sulfur from contaminated air in sufficient quantity to corrode heat exchanger equipment if they are not properly inhibited. A summary of the situation in eight eastern U. S. cities begins on Page 79.

INHIBITORS FOR COOLING WATER should be applied at high concentrations initially to produce a protective film quickly. This film can be maintained at substantially lower dosage levels using continuous treatment. More details on this method are given in an article beginning on Page 81.

PETROLEUM REFINERY crude oil distillation units suffer less corrosion damage than estimates have indicated. An extensive study into the economics of refinery corrosion is presented on Page 87.

WATER TREATMENT PLANTS can be successfully and economically protected from excessive corrosion by cathodic protection. Details of six years of operating experience are given on Page 95.

ZINC ANODES should be used more commonly to protect ships, an article beginning on Page 99 recommends. Results of trials up to three years' duration using ASTM Special High Grade zinc anodes are revealed.

CHROMIUM PLATING to prevent stress corrosion cracking of AISI 410 steel in 300 F water gave anomalous results. Some of the reasons for these results and reports on tests pointing to other possible dangers from using chromium plate are given in an article beginning on Page 105.

DIETHANOLAMINE used in refineries to remove hydrogen sulfide from refinery gases can cause severe corrosion damage. Experience with an operating unit is given in detail beginning on Page 111.

UNSYMMETRICAL DIMETHYLHYDRAZINE rocket fuels, which have been adopted as a substitute for fuels currently used in high performance rockets, are rated against numerous metallic and non-metallic materials. Turn to Page 115.

WROUGHT IRON exposed in fresh and salt water at the Panama Canal corrodes at about the same rate as mild steel initially, but after eight years the steel shows significantly greater weight loss. Results of long term tests of wrought iron are given in an article beginning on Page 120.

INTERGRANULAR STRESS CORROSION cracking of alpha aluminum bronze can be reduced by additions of alloys as indicated by application of equilibrium grain boundary segregation principles. Turn to Page 127 for a report on an effort to predict the effect of alloy additions to prevent stress corrosion cracking.

WATER SIDE CORROSION under heat flux conditions involving high process side temperatures is interestingly explored in an article beginning on Page 131. Chromates reduce the amount of deposited scale.

INTERCRYSTALLINE CORROSION of chromium-nickel steels depends on the amount of precipitated chromium carbide and on the redox potential of the corrodent, it was concluded after a series of tests reported in an article beginning on Page 138.

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Corrosion

Published monthly as its official journal, by the National Association of Corrosion Engineers, Inc., at Houston, Texas, U.S.A., as a permanent record of progress in corrosion control.

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AN EDITORIAL

The "Cost of Corrosion" Problem

NUMEROUS requests from a wide variety of sources come to the National Association of Corrosion Engineers concerning the cost of corrosion. Most of these requests ask for data of minute specificity, for example, "How many dollars were spent for paints to protect structural steel from atmospheric corrosion last year?" or, "How many gallons of paint were applied in 1959 by spray gun to prevent corrosion inside chemical plants in New Jersey?"

These and other equally specific questions are designed to get data analogous to that which would be obtained if the following were asked of an appropriate source: "How many boxes of oranges were shipped east from Pomona County in 1960?" On the surface, perhaps, it seems no more difficult to answer the question about oranges than to answer the one about paint in New Jersey.

NACE is unable to answer these specific questions, nor does it know of any source that can. There is even some doubt that questions about dollar consumption of corrosion control items ever can be answered accurately. This is not because efforts have not been made by NACE and others to get the answers. The difficulty stems from the complexity of the corrosion problem, which involves itself intimately in other maintenance and housekeeping activities.

There is also the problem involved in the ambiguity of the corrosion factor applied to materials and environment. For example, everyone concedes that stainless steel valves are sold most often because of their corrosion-resistant characteristics. Those conversant with corrosion reactions know also that many low-cost cast iron valves are used to handle corrosive substances efficiently. If one learns how many stainless steel valves were bought in the Q-product industry in 1959, are the data relevant if the same industry also bought many cast iron valves to handle both corrosive and non-corrosive materials? How many valves did the industry buy for corrosion-control purposes?

Or, take another area of interest. Inhibitors of one kind or another are used in most petroleum refineries. Most use several kinds, often in different parts of their plants and for different reasons. One group of chemicals helps limit corrosion caused by the oil itself; another group is used to reduce corrosion by water. Some act with both. Assume that one could get the exact kind, quantity and cost of all inhibitors used by one refinery and relate it to output. In other words, the complete story on inhibitors for one refinery. Can these data then be applied to another refinery 10 miles or 10 states away? Or, all refineries in the United States?

Few corrosion engineers will agree that this is possible. Another refinery not only may use different inhibitors, in different quantities, but the types and quantities of inhibitors used will vary from time to time to match changed crude input or modification of the types of refined products produced.

Examples of this kind could be repeated almost endlessly. That these are facts is no consolation to the market investigator who needs to come up with some kind of an estimate on what his company can expect to sell. NACE is sympathetic to this need and wishes it could do more than it does to answer the questions fully.

It is to be hoped that in the future more companies will adopt the policy of separating corrosion damage, control and replacement costs from obsolescence and maintenance accounts where most corrosion-connected items are to be found now. Such a change would give a truer picture of corrosion problems and put corrosion control programs in the proper perspective versus other cost items of operation.

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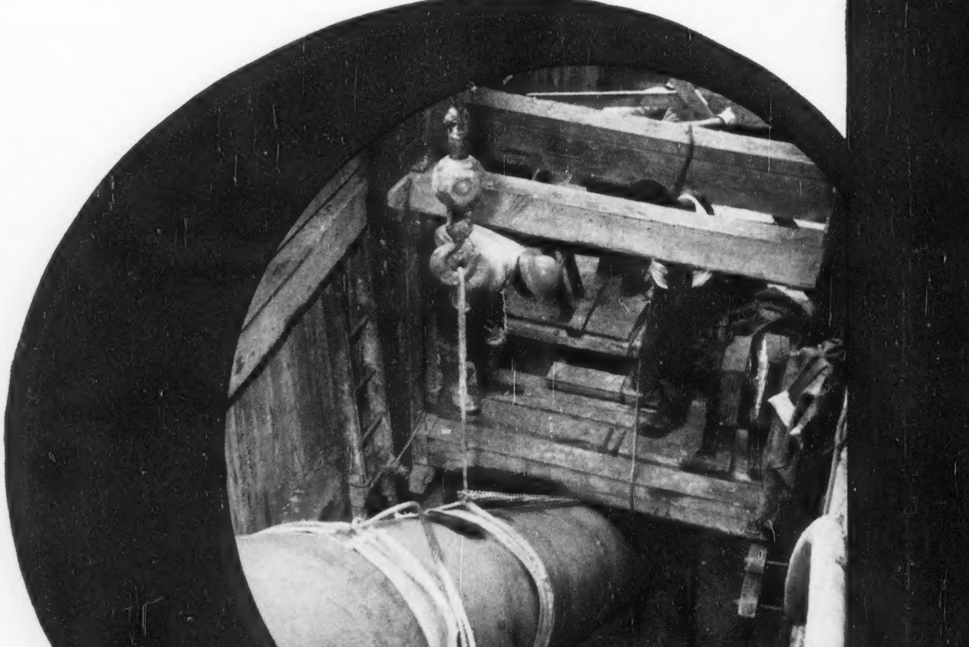

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TECHNICAL TOPICS

Cathodic Protection Used to Control Corrosion of SERVICE STATION UNDERGROUND EQUIPMENT*

M. J. Olive
Arkansas Fuel Oil Corporation
Shreveport, Louisiana

Abstract

Explains economic importance of controlling corrosion of service station underground equipment. Describes methods of determining corrosion probabilities, lists coatings suggested for service station use and explains importance of soil resistivity. Shows how current requirements are determined for cathodic protection of underground storage tanks. Describes protection by sacrificial anodes and by rectifiers. Also gives tabular data on economics of cathodic protection. Illustrations show typical installations. Graphs give information for determining anode currents required.
3.2.1

CORROSION LOSSES annually in the petroleum industry are estimated at over 300 million dollars, and a large portion of this corrosion loss is paid by the service station owner or operator. Consequently, recognition and prevention of corrosion on service station equipment is economically important.

Several possible methods of preventing corrosion of service station equipment could be used, but the combination of cathodic protection and coatings have proved to be the most effective and economical for underground corrosion.

Determining Corrosion Probabilities

Because corrosion preventive measures should not be taken unless they are economical, the probability of serious corrosion damage should be determined. Most underground corrosion is due to corrosive action of soils, stray currents and/or bi-metallic couples.[1]

When a new service station is to be built, soil resistivity, change in resistivity and make up of the soil in which gasoline storage tanks are to be buried will give an index to the amount of corrosion than can be expected. Soil resistivity can be determined by instruments[2] used on the building site or by soil samples for checking in a central laboratory.

Soil resistances are measured in ohms per cubic centimeter. If soil resistivity is below 3000 ohms, corrosion can be expected and protective measures should be applied. If soil resistance is below 1000 ohms, protection is necessary if continued service of the tank or underground structure is desired. If the resistivity is above 5000 ohms, corrosion damage would be slight and uneconomical to prevent.

If the soil being checked contains cinders or debris from construction such as metal cans, scrap metal, etc., corrosion can be expected regardless of the soil's resistivity because debris and cinders cause localized corrosion cells when in contact with the buried tank. Such debris should be eliminated during construction backfilling operations when possible.

Analysis of the probability of corrosion damage is dependent on the number of soil tests taken: the greater number of tests, the more accurate the analysis. Tests should be made at the lowest depth which tanks will be buried and at about the middle of the tanks. Experience has shown that changes in soil resistivity from the top of the tank to its middle affect the corrosion rate considerably.

Sand cannot be relied upon as a protective measure when used for backfill. Sand adsorbs ions from the surrounding soil and will become as the parent soil. Sand does help minimize corrosion but will not prevent it for any great length of time.

Coatings for Service Station Uses

Hundreds of coatings are available for protecting buried steel from corrosion.[3-9] Economics and application problems limit these coatings to six basic types for service station use: (1) hot applied pipeline coatings, (2) cold applied mastic coatings, (3) plastic tapes, (4) thin film plastics, (5) solvent or heat applied enamel pipeline tapes and (6) solvent or hot dipped asphalt or cold tar coatings.

(Continued on Page 10)

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*Revision of a paper titled "Corrosion and Its Prevention in Service Station Underground Equipment" presented at a meeting of the Houston Section, National Association of Corrosion Engineers, September 8, 1859, Houston, Texas.

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(Continued From Page 9)

In corrosive conditions, coatings should not be used alone for protection. Breaks or holidays in the coating will occur during application of the coating or installation of the tank. Corrosion will be concentrated at these small holidays, resulting in quicker penetrations and failures than with uncoated tanks. Because service station tanks normally are ordered long before soil conditions are known at the building site, tanks should be coated before installation and further protected cathodically.

Cold applied mastic coatings have proved to be the most economical type coating for underground storage tanks. This mastic can be brushed or sprayed over a surface that has been degreased and wire brushed. This mastic can be purchased in a formulation that is insoluble in hydrocarbons and that can be patched on the job site.

TABLE 1—Maximum Allowable Current Output From Galvanic Anodes (Milliamperes per Pound of Anode)

Type Anode	Useful Life of Anode	
	10 Years	15 Years
Magnesium	5.7	3.8
Zinc	3.8	2.5
Aluminum	5.2	3.5

NOTE: Above figures based on anode efficiencies of 50% for magnesium, 90% for zinc and 35% for aluminum. These figures can be applied to any weight anode to determine its maximum output for any desired life. For example, a 17-pound magnesium anode would have 3.8 x 17 or approximately 65 milliamperes maximum output for 15 years' life.

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Heat or solvent tapes when applied give a heavy thick layer of coating with glass reinforcement. These types cost more than the mastic coatings because of greater application costs.

Plastic tapes have the disadvantage of being easily damaged and lose their bond if gasoline contacts the adhesive.

Thin film plastics show excellent properties but generally require sandblasted or shot blasted surfaces for application—thus increasing the cost to a point making such protection uneconomical for service station use. Coal tar epoxy shows good promise if costs can be lowered.

Use of High Resistance Soil

Where fills are required, use of high resistant soil is an effective method of reducing the possibility of underground corrosion on service station equipment. Sandy loam, which is generally available, is a high resistant soil. Fills should not contain debris or junk which would add to the corrosion problem.

Cathodic Protection Method

Impressed currents and sacrificial anodes are used to apply cathodic protection to underground structures such as storage tanks for corrosion control.[1,10–13] Protective current must be applied to the structure being protected in an amount sufficient to prevent current flow from any point on the structure's surface into the soil. This current has been recommended to be a minimum of 0.85 volts negative to a copper-saturated copper sulfate half cell in the immediate proximity of the structure.[14]

Determining Current Required

The essentials in designing a cathodic protection system for service station equipment are to determine the protective current required, source of current and the electrolyte through which the current must pass.

Current amount depends on size of the underground structure, the coating and the soil resistivity. A test can be made to determine the amount of direct current required to raise the structure to negative 0.85 volts potential. This test consists of installing a current discharge point (usually a steel rod sunk in the earth) approximately in the location of any possible permanent anodes. The amount of direct current from an internal source such as a welding machine, battery charger or batteries is increased until the potential of the structure reaches —0.85 volts. The amount of current required to obtain the —0.85 potential then is used in designing a cathodic protection system for the structure.

TABLE 2—Resistance to Earth of Galvanic Anodes in Soil of 1000 Ohms per Cubic Centimeter

Anodes	Ohms
4″ x 20″ Magnesium Anode in Suitable Backfill	5.5
4″ x 5′ Magnesium Anode in Suitable Backfill	3.0
½″ x 3″ x 3′ Zinc Anode in Suitable Backfill	4.0
½″ x 3″ x 5′ Zinc Anode in Suitable Backfill	3.0
4″ x 20″ Magnesium Anodes Stacked 2 Deep Vertically	3.5
4″ x 20″ Magnesium Anodes Stacked 3 Deep Vertically	2.5
½″ x 3″ x 3′ Zinc Anodes Stacked 2 Deep Vertically	2.5
½″ x 3″ x 3′ Zinc Anodes Stacked 3 Deep Vertically	1.8

Notes:
The above values will vary somewhat depending on the size of the auger holes used, amount of backfill above and below the anodes, type of backfill, and spacing between anodes (in the case of vertical stacks of anodes).
Resistance of any of the above anodes in soils having resistivity other than 1000 ohms per cubic centimeter may be obtained by direct proportion: i.e., a 4″ x 20″ magnesium anode in 1,350 ohms/cc soil would have 5.5 x 1.35 or 7.4 ohms resistance.

Current required also can be estimated rather close by calculating the net area of the structure to be protected (subtracting estimated coated area from total tank area) and multiplying by 3 milliamperes per foot. This will give an estimated current in milliamperes needed for controlling corrosion on that specific tank. This method is particularly accurate when field experience shows the amount of coverage expected to be protected by the tank coatings.

Soil resistivity not only determines the probabilities of corrosion occurring on underground tanks but also determines the amount of current from sacrificial anodes and the groundbed resistance of impressed current anodes. Soil resistivity is a big factor in the economics of controlling corrosion: the higher the resistivity the more expense required for cathodic protection.

Protection by Sacrificial Anodes

Zinc and magnesium are the two materials most generally used for underground sacrificial anodes. Aluminum anodes also are used. Magnesium has a solution potential of —1.55 volts compared to a —1.1 for zinc. Therefore, in low resistivity soils (1000 ohms per

(Continued on Page 12)

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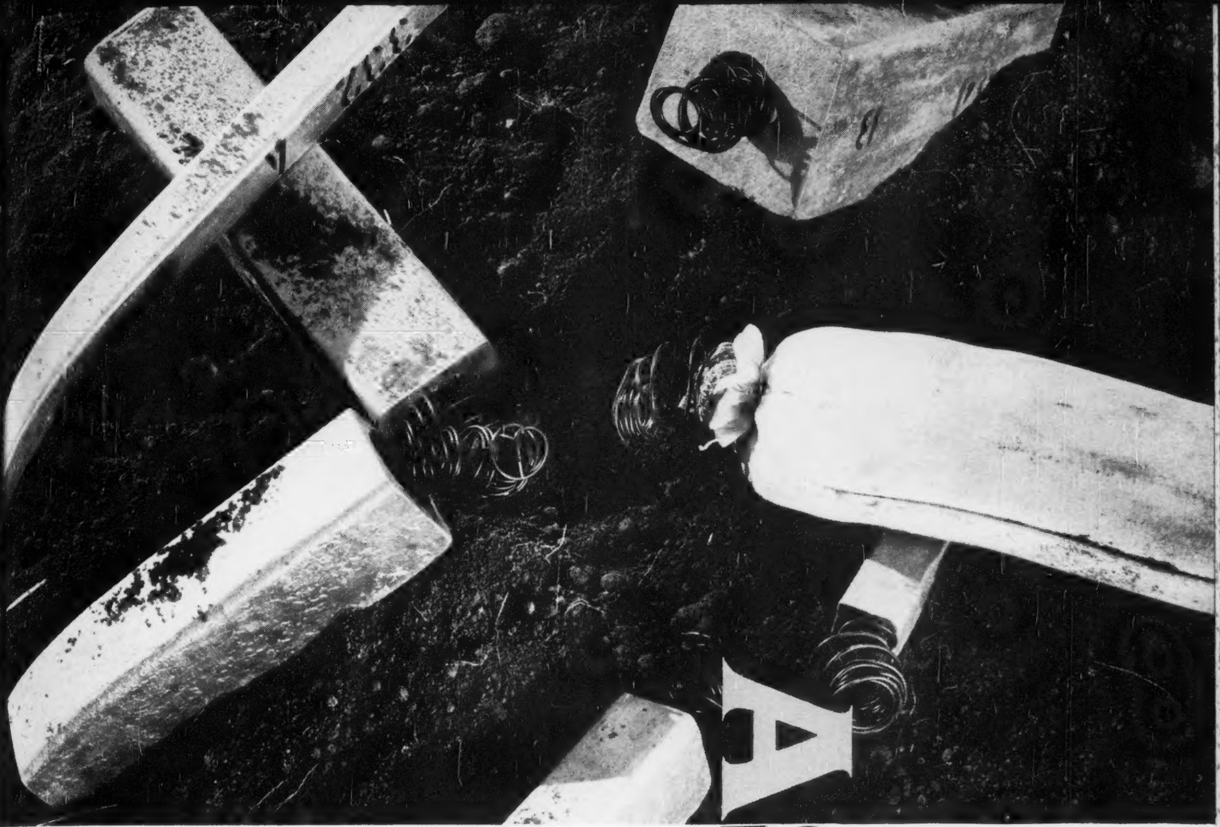

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Continued From Page 10)

cubic centimeter), zinc can be used; in higher resistivity soils, magnesium.

After the amount of current required is determined and the parent soil resistivity is measured, anode resistance can be calculated from Figure 1 and Tables 1, 2 and 3. By using the formula

$$I = \frac{E}{R}$$

where I is current, E is potential and R resistance, the amount of current output from a single anode or group of anodes can be calculated. By comparing the current required for cathodic protection with the output current of various groupings of anodes, the correct number of anodes can be determined. The cathodic protection system can be designed for any desired anode life from the data in Table 1.

Anodes are installed around the storage tanks and connected to each tank by a metallic conductor as shown by a typical installation in Figure 2. Some types of anodes and typical installation are shown in Figure 3.

Sacrificial anodes must have suitable backfill around the anode to insure steady and unform current discharge. This backfill serves to isolate the anode chemically and acts as a means of transmitting current to the surrounding soil, thus reducing the contact resistance between anode soil. Backfill normally recommended consists of 75 percent gypsum, 20 percent bentonite and 5 percent sodium sulfate.

Protection by Rectifiers

The same principles and calculations used for sacrificial anodes can be used for determining cathodic protection of underground structures by rectifiers and graphite groundbeds. If the current requirements are high, rectifiers may be needed or may be more economical than sacrificial anodes.[15-17]

Rectifiers convert alternating current to direct current so that larger amounts of current can be used for protection than can be supplied by anodes. Rectifiers also permit variable voltages for flexible adjustment of current output from the groundbeds. Another advantage is that additional voltage can be applied by changing the steps in the transformer as required by dry weather or any increase in circuit resistance.

An easy method of checking the cathodic protection system's performance is provided in a voltmeter and ammeter installed inside the rectifier unit, as shown in Figure 4.

A typical rectifier system for cathodic protection of service station tanks is shown in Figure 5, consisting of rectifier, graphite-coke groundbed and cable connections. Rectifier and groundbed sizes are determined by the current requirement and soil resistivity. The graph given in Figure 6 can be used to determine the groundbed resistance of various anode groupings at any soil resistivity.

The groundbed anode consists of a graphite rod usually 3 inches in diameter by 60 inches long, surrounded by a prepared coke backfill. After a hole is augered from 8 to 12 inches in diam-

(Continued on Page 14)

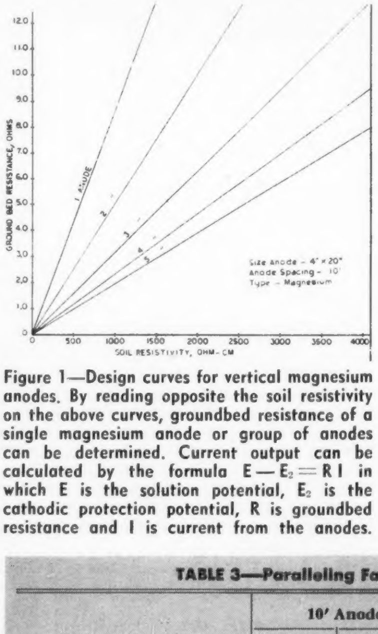

Figure 1—Design curves for vertical magnesium anodes. By reading opposite the soil resistivity on the above curves, groundbed resistance of a single magnesium anode or group of anodes can be determined. Current output can be calculated by the formula $E - E_2 = RI$ in which E is the solution potential, E_2 is the cathodic protection potential, R is groundbed resistance and I is current from the anodes.

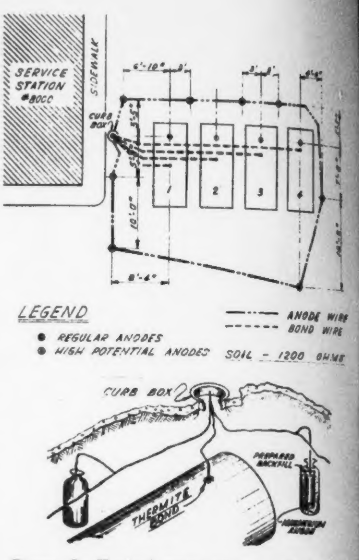

Figure 2—Typical magnesium anode installation for service station tanks.

Technical Papers to Be Published in November

Corrosion of Tube Materials by Boiler Sludge, by E. Howells, T. A. McNary and D. E. White

Corrosion Problems in the Use of Salt Solutions as Packer Fluids, by C. M. Hudgins, W. D. Greathouse and J. E. Landers

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High Temperature Furnace Corrosion, by R. D. Merrick

Cracking of Low Carbon Steel by Ferric Chloride Solutions, by Mary Boehm Strauss and M. C. Bloom

Things New or Unusual in Mitigation of Corrosion in the Utilities Field, by E. H. Thalmann

TABLE 3—Paralleling Factors for Galvanic Anodes

Effective Anode Length	10′ Anode Spacing			15′ Anode Spacing		
	4 Anodes	8 Anodes	12 Anodes	4 Anodes	8 Anodes	12 Anodes
3′	1.26	1.34	1.40	1.16	1.24	1.27
4′	1.30	1.43	1.48	1.20	1.28	1.33
5′	1.34	1.49	1.55	1.24	1.33	1.37
6′	1.38	1.55	1.63	1.27	1.38	1.42
8′	1.45	1.66	1.74	1.32	1.46	1.51
12′	1.57	1.83	1.97	1.42	1.59	1.67

Notes:
The effective lengths cover individual anodes of various lengths in backfill as well as two or more anodes stacked vertically in suitable backfill.
This table is used in conjunction with anode resistance table. For example, a 4″ x 5′ magnesium anode will have about 3.0 ohms resistance in 1000 ohms per cc soil while its effective length in suitable backfill may be 6′. Eight such anodes in parallel in 1000 ohms/cc soil would then have a combined resistance of:
(3–8) x 1.55 Factor of .58 Ohms at 10′ Spacing or
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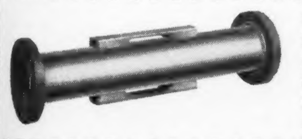

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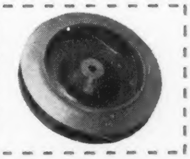

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eter, the anode is placed in the center of the hole and coke packed around the anode, as shown in Figure 7. The coke gives a lower contact resistance and allows gas to escape from around the anode. The number of anodes installed is determined by how much current is being discharged and the groundbed resistance needed.

Economics of Cathodic Protection

One major service station operator has used cathodic protection on 80 stations at a cost of $19,500 at an average cost of $244 per station. The average station had three 3000-gallon tanks which were coated with a cold applied mastic or a coal tar paint. All tanks were protected by magnesium anodes except one. Records indicated that an average tank would last 12 years or less without protection from corrosion. Some tanks lasted only one to two years in severe conditions. By extending tank life an additional 12 years by cathodic protection, a saving of $130,000 was estimated—over 600 percent return on the investment.

Data on the economics of this operator's use of cathodic protection are given in Table 4.

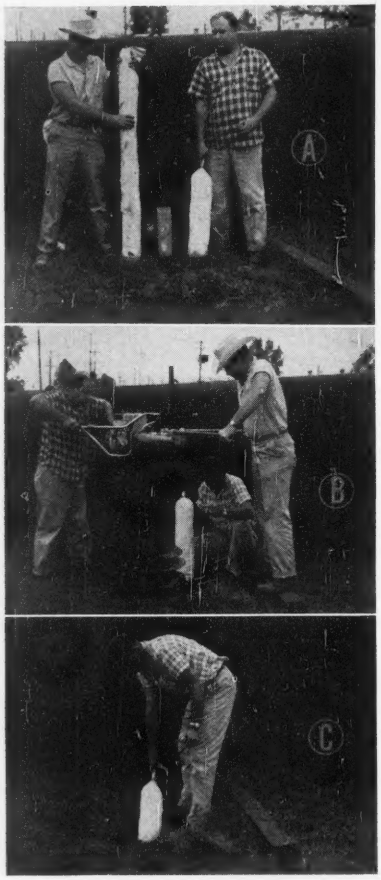

Figure 3—Installing sacrificial anodes. Photograph A shows three popular anode sizes used: left to right they are the 5-foot high potential, regular pipeline anode and the regular high potential. Anodes usually have a 10-foot lead wire and are pre-packed with backfill in a cloth sack. Photograph B shows the hole being augered for the anode. Photograph C shows the packaged anode being lowered into the hole.

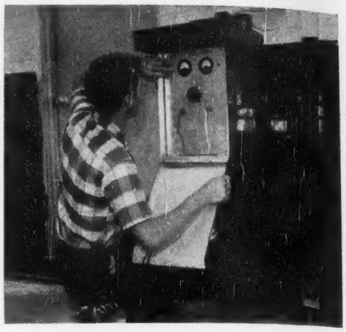

Figure 4—Typical rectifier mounted at rear of a service station. Instruments indicate voltage and amperage of the unit which indicate steady operation of the unit. A variable step transformer regulates the voltage so that current output can be regulated.

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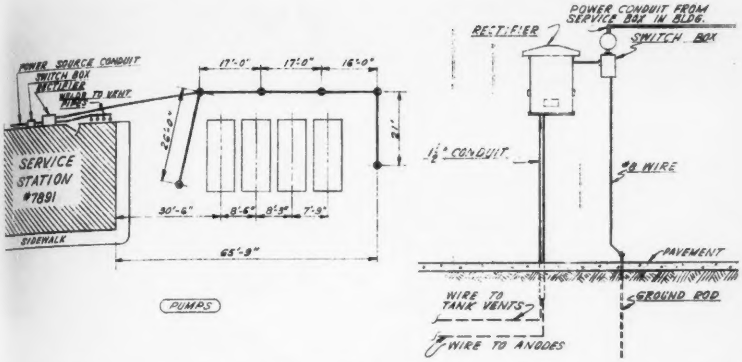

Figure 5—Typical rectifier and graphite anode installation for cathodic protection of service station underground equipment.

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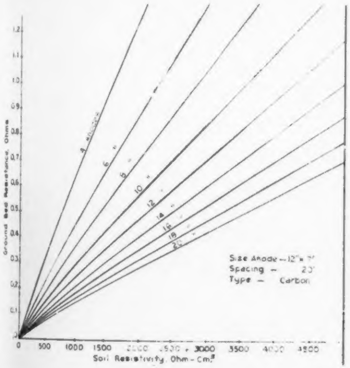

Figure 6—Design curves for vertical carbon anodes. Graph above can be used to determine groundbed resistance of various anode groupings at any soil resistivity. Station operator can determine number of anodes required to obtain current desired from any rectifier voltage.

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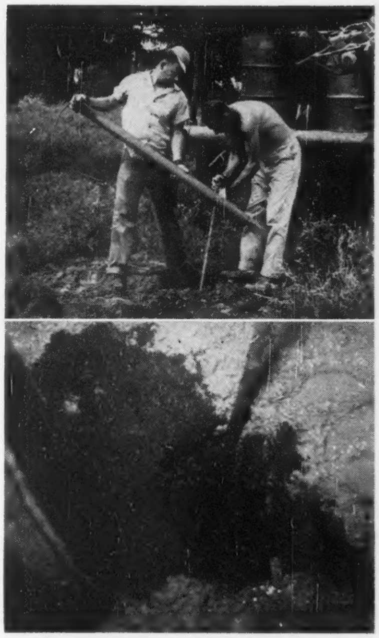

Figure 7—Top photograph shows a 3-inch by 60-inch graphite ground anode being installed in a 12-inch diameter hole. A special coke backfill (lower photograph) is required for this type installation. The coke is packed around each ground anode about 12 to 24 inches above the anode's top and about 6 to 8 inches below its bottom. This gives a larger effective anode and insures longer life of the graphite core.

Cathodic Protection Symposium Scheduled for January

Three Technical articles on methods and experience in underground cathodic protection are scheduled for publication in the January issue's Technical Section.

TABLE 4—Economic Study of Cathodic Protection of Service Station Underground Storage Tanks

Division	Number of Stations Protected	Material	Labor (3 Men)	Trav. Exp. & Labor 1	Total	Total Cost per Division	Economic Life of Station	Avg. Unprotected Years 2	Life of Tanks Protected Yrs. 3	Cost of Tank Replacement per Station 4	Total Savings 5
Alabama	2	$136.50	$36.90	$103.90	$277.30	$ 554.60	25 Yrs.	12	25	$2,300.00	$ 4,045.40
Arkansas	11	136.50	36.90	103.90	277.30	3,050.30	25 Yrs.	12	25	2,300.00	17,649.70
Georgia	1	136.50	36.90	103.90	277.30	277.30	25 Yrs.	12	25	2,300.00	2,022.70
Louisiana	37	136.50	36.90	31.30	204.70	7,573.90	25 Yrs.	12	25	2,300.00	61,426.10
Mississippi	20	136.50	36.90	103.90	277.30	5,546.00	25 Yrs.	12	25	2,300.00	31,254.00
Tennessee	1	136.50	36.90	103.90	277.30	277.30	25 Yrs.	12	25	2,300.00	2,022.70
Texas	8	136.50	36.90	103.90	277.30	2,218.40	25 Yrs.	12	25	2,300.00	11,581.69
Total	80					$19,497.80					$130,002.20

Notes:
1. Travel expenses are computed on a 200 mi. average travel. In other than adjoining states, it is assumed, as has been the case, that a station was protected in the preceding state.
2. In the past, this figure has been considerably lower on corrosive stations. The heavier gauge steel in use today would give a longer life, but this figure is considered a maximum.
3. In some cases, a replacement of anodes at the original cost, would be required to attain this life. In all cases, by replacement of anodes, almost any desired tank life can be attained.
4. This is an estimated cost based on current installation costs.
5. These savings are based on the assumption that 80% of the stations protected would have required at least one tank replacement during the 25 year life of the station.

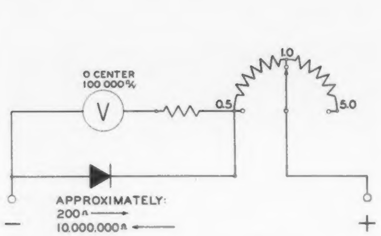

Figure 1—Meter protection circuit. Germanium diode was connected across the coil and the series resistance to protect the meter's one-volt and higher scales. When current surge was reversed, the diode conducted and its resistance became about 200 ohms, limiting the current through the element to a safe value.

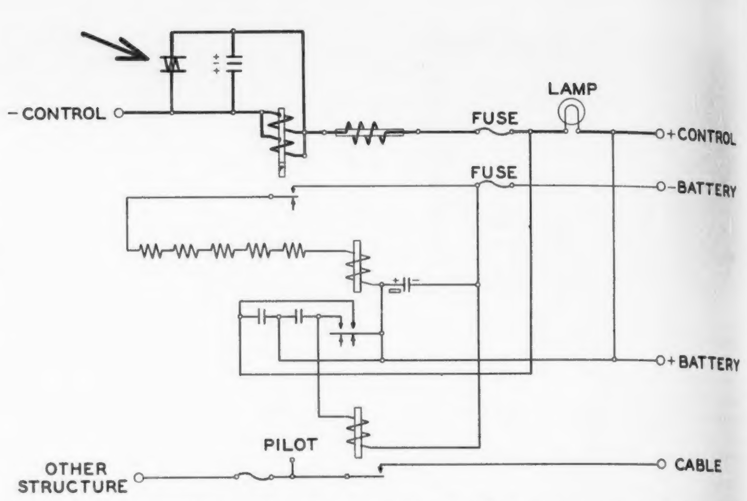

Figure 2—Surge protection for polar relay magnets. Arrow indicates the protective diode wired in parallel to protect the relay magnets. Two diodes were used, one for each polarity.

Abstract

Describes use of germanium diodes to protect meters and electrolysis drainage switches from current surges resulting from power interruptions at railway substations. Also explains circuitry used to eliminate damage to polar relay magnets in electrolysis switches. 7.7

Experimental Circuits Stop Electrolysis Switch Damage★

L. L. Swan
Illinois Bell Telephone Company
Chicago, Illinois

ELECTRONIC COMPONENTS in corrosion control equipment have been damaged by high voltage currents resulting from normal switching on a power system. This article describes a case history in which electrolysis switches were being destroyed by transient currents.

Electrolysis switches are used by Illinois Bell Telephone to drain stray currents from its telephone cables back to the negative bus of traction power systems when the substations are operating. The switches open this circuit to prevent current from flowing back to the telephone cables when the substation is shutdown.

Damage to Test Meters

These switches also are used to drain current from the cable to the traction rail at points on the cable being attacked by stray currents. At an installation such as this, a meter being used for test readings was seriously damaged by a high voltage negative current when the subway power was suddenly interrupted.

To solve this problem, a germanium diode was connected across the coil and the series resistance for the half volt scale on the meter as shown in Figure 1. With the diode in the circuit, the meter element was protected on the one volt or higher scales. Readings were made of low positive potential with little error because the diode had a resistance of about 10 megohms. When a current reversal occurred, the diode conducted and its resistance became about 200 ohms. This limited the current through the element to a safe value. The deflection seldom was more than half scale before the current surge was dissipated.

Damage to Polar Relay Magnets Solved

Successful protection of the meter circuit suggested the idea that high negative current surges might effect the magnets used for biasing the polar relays in the electrolysis drainage switches. In some locations, these relays had required frequent adjustment and sometimes replacement in less than a year of service.

To check this effect, experiments were set up, using a surge of 150 volts across the relay control circuit of a drainage switch. Current over three amperes flowed momentarily in the polar relay winding which resulted in changing the operate and release currents even in the new alnico type relay.

For greater protection than that obtained with germanium diodes, experiments were made using copper oxide rectifiers. Such a rectifier with a voltage drop of 0.8 volts at three emperes was connected in parallel with the relay. Current in the relay winding was limited to 80 milliamperes. This value (called the reverse "soak" current) is used in adjusting these polar relays before putting them in service. The circuit is shown in Figure 2. The arrow indicates the protective diode. Two diodes were used, one for each polarity. Because the rectifier units do not conduct until the current required to operate the relay is exceeded, the rectifiers do not interfere with operation of the drainage switches.

This electrolysis switch with the experimental protective circuits was adjusted in the shop, the polar relay sealed and the unit installed on the telephone cable. It operated for 18 months until a power failure occurred near its location.

The badly damaged switch was returned to the shop for inspection and repair. Some of the wiring had vaporized, fuses were blown, the contactor had welded and one of the rectifier units had short circuited, but the polar relay operated at the same currents for which it had been adjusted 18 months before. This was unbelievable performance.

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Technical Papers to Be Published in December

Effect of Various Curing Agents on Chemical Resistance of Epoxy Resins, by Ronald L. DeHoff

Internal Carburization and Oxidation of Nickel-Chromium Alloys in Carbon Monoxide, by B. E. Hopkinson and H. R. Copson

Ship Coating of Structural Steel, by John D. Keane and Joseph Bigos

Impressed Current Anodes for Cathodic Protection, by Walter P. Noser

High Temperature Corrosion in Refinery and Petrochemical Service, by E. N. Skinner, J. F. Mason and J. J. Moran

Inhibition of Corrosion of Commercial Aluminum Alkaline Solutions, by J. Sundarajan and T. L. Rama Char

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★ Extracted from a paper titled "Protection of Corrosion Equipment From Damage by Transient Currents" presented at a meeting of the 16th Annual Conference, National Association of Corrosion Engineers, Dallas, Texas, March 14-18, 1960.

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History and Development of

Some Problems Associated with CONTRACT CHEMICAL CLEANING★

Charles M. Loucks
Consulting Chemist
Westlake, Ohio

Introduction

THE SUBJECT of controlling corrosion during chemical cleaning has received considerable attention by engineers in industry and by members of the National Association of Corrosion Engineers particularly. At the first meeting of the NACE T-8 Refinery Corrosion Committee in St. Louis in 1957,[1] the subject was discussed. It was considered important enough to justify a special Task Group T-8A[2] to concern itself with that problem alone. That committee has been active and reports of its meetings are in the records of NACE.

In spite of this, however, it is important to inquire in industrial plants where chemical cleaning is being done, if there is a record of improved technology and more attention to corrosion control. There has apparently been no marked improvement, so far as the author's observations are concerned. So, because corrosion control during chemical cleaning is a matter of considerable importance, it is interesting to look for reasons for the lack of improvement.

This discussion concerns primarily chemical cleaning done with strong mineral acids by service contractors. The author has spent 16 years with a chemical cleaning contractor. In this area of equipment maintenance, it is acknowledged that a corrosion control problem exists.

History of Chemical Cleaning

To acquire perspective about chemical cleaning, a brief review of the background recorded in technical and trade literature is worthwhile. Although the practice of chemical cleaning is relatively young, many interesting reports are to be found. As soon as industrial equipment came into general use, maintenance problems involving scale and corrosion products plagued the users. When steam engines and steam generating equipment reached considerable size, maintenance problems became significant. Because little was known of the science of water treatment, fouling was rapid and severe. So it is no wonder operators were willing to try anything.

Many products of vegetable and mineral origin have been used. For example, petroleum products, including crude oil, were used to remove boiler scale, with some measure of success. The Transactions of The American Society of Mechanical Engineers of 1888[3] contains a very interesting report by Mr. Lyne, member of the Society, and engineer at the Jersey City Electric Light Company, on the subject "Kerosene to Prevent and Remove Scale." After describing experiments with kerosene and its actual use in boilers, he closes by saying, "Some engineers advance queer theories against the use of kerosene but I must assert that, for the most part, they are only imaginary. We have as yet found no objections in our experience. Our boilers do not lift their water, they are free from scale and our fuel bill is greatly reduced."

Potato Skins Plugged Valves

During the discussion that followed Mr. Lyne's paper, Mr. Ridgeway reported successful use of 44 to 50 gravity crude. Mr. Cooper said he is familiar with Allen's "Anti-Lamina," a petroleum derivative. He also mentions a Eucalyptus Extract and says, "I met with wonderful statements about it while sojourning on the West Coast and sought to prove them." Mr. Babcock knew of the use of kerosene some 20 years ago for removing sulfate of lime scale from a boiler. Mr. Lyne had a friend who used potatoes, skins and all, and had trouble with the skins plugging valves on the system. Then Mr. Engle got to his feet and said, "I rise to defend the potatoes. I think that potatoes are in common use in some parts of the country, and I know of at least one case in which they are used with good effect . . . I believe potatoes act very much as the white of an egg does with coffee. I cannot see the necessity either for putting potato skins into the boiler. The essence of the potato is all that is necessary. The potatoes mashed up have a sufficient effect without the skins."

Abstract

Author believes little more attention is being paid to corrosion control in chemical cleaning operations than was common in 1957 when the first NACE committee on the subject was organized. History of chemical cleaning is reviewed, with references to the literature dealing with the use of petroleum products, potatoes and other materials. First use of acids is described and some engineers' comments on use of acids are reported.

Following the introduction of inhibited acids for cleaning, the growth of contract cleaning is described. Some laboratory and field experience with cleaning by inhibited acid is described, and some of the corrosion and safety hazards examined.

In considering the contract cleaning of plants with acids, the author cites the difficulties faced in attempting to establish specifications for the work in advance of contract letting. He deplores the practice of letting acid cleaning on the lowest bid without a full understanding between the parties of what is to be done.

Writer suggests that the nature of the acid cleaning process is such, the potential hazards to persons and equipment so serious that industry would be advised to seek professional type services rather than let work on low bids. Some mention is made of cleaning agents other than hydrochloric acids and why contractors so far have shown little interest in them. 49 references. 5.9.2

Some may feel that materials like these were harmless, and if they did no good, they probably did no harm. But in 1899 in The American Machinist,[4] a Mr. Cary discusses many chemicals used for cleaning boilers. He includes caustic soda, sal soda, acetic acid, tannin and phosphate salts. But he says, "Sal ammoniac is most undesirable for use in a boiler due to the liberation of hydrochloric acid following its introduction into the boiler. This acid leaves the boiler in a vaporous form with the steam, corroding the boiler, the piping and nearly everything it comes in contact with." He also condemns "boiler quacks" and says, "They are often tricky manipulators, able to give an apparent exhibition of the wonderful disincrusting power of their purges. I caught one at one time cracking the scale out of a boiler by blowing it empty of its water under steam pressure and then flooding it suddenly with cold water. In another case, I found that one of these manipulators had about ruined a boiler by first giving it a dose of muriatic acid before introducing his compound."

During the next 30 years, there were frequent references to the use of alkalis, alkaline salts, vegetable materials, weak acids and even carbon dioxide. There were occasional reports of the use of mineral acids, particularly for cleaning power equipment. The early trade literature devoted to refinery processes contains very little about cleaning techniques. But by 1916, it was not unusual to read of hydrochloric acid being used for cleaning steam condensers. In Power, 1916,[5] Mr. Hirshfeld of the Edison Illuminating Company of Detroit, describes condenser cleaning methods in some detail. Under the heading "The Chemical Method," he says, "The chemical method has been used to some extent in Europe and possibly in this country. It consists in feeding into or through the tubes a dilute chemical solution that will attack the deposit and leave it so it can be easily brushed or washed out by circulating water. Such information as is available with regard to the process does not indicate that it has been particularly successful. The cost of chemicals combined with the danger to packing, bimetallic contacts and tube metal would seem to argue strongly against it."

Acid Is Used Successfully

But in the next few years, there were numerous reports of successful use of acid with little damage to copper alloy tubes. Some people painted the water boxes to protect the ferrous metal parts.

On the subject of cleaning other power facilities, there are such comments as that by H. M. Tombs of Chicago in Power, February, 1923,[6] under the department heading "Practical Ideas." He described the use of 20 carboys of muriatic acid for cleaning a boiler feed line and says the cleaning

(Continued on Page 20)

★ Revision of paper titled "Controlling Corrosion While Chemical Cleaning" presented at the 16th Annual Conference, National Association of Corrosion Engineers, Dallas, Texas, March 14-18, 1960. Abstracted under title "Chemical Cleaning Poses Corrosion Problems" published in Oil and Gas Journal, Vol. 58, No. 32, 97-98 (1960) August 8.

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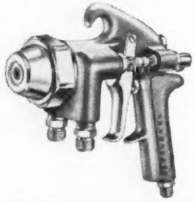

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Chemical Cleaning—

(Continued From Page 18)

required three 24-hour periods but "did not harm pump, valves or gaskets."

In April, 1923, also in Power[7] under "Comments by Readers," Mr. Gross warns of corrosive hazards during and after use of hydrochloric acid. He reports that 20 years ago certain engineers used muriatic acid in their boilers and "needless to say, this resulted disastrously in many instances . . . The use of acid is, in my opinion, poor practice." But the reports do not all agree. In the May 29, 1923, issue,[8] another reader, Mr. Benefiel, says, "Mr. Gross is unduly apprehensive as to corrosive effects of this acid. It is only mildly corrosive as to iron and brass also . . . In the industry where I am employed, muriatic acid is bought by the carload. Naturally, the engineers use it quite freely for removing lime from injectors, gas engine jackets, etc. And it is never diluted but we have no trouble from corrosion. It is possible that Mr. Gross had sulfuric acid in mind, in which case the results would be much more serious."

As late as 1941, one finds in the trade literature[9] comments such as "Muriatic acid will dissolve anything it comes in contact with unless retarders are added." And the suggested retarder is one quart of carbon tetrachloride per five gallons muriatic acid, which "retards the action 90-95%."

Inhibitors Become Known

Considerable attention had been given earlier to acid pickling techniques by the steel industry and by 1920 the use of inhibitors was becoming generally known. In 1928, Chappell, Roetheli and McCarthy of the Massachusetts Institute of Technology say in Industrial Engineering Chemistry,[10] "The use of inhibitors has long been known in industry and in recent years very powerful ones have appeared on the market." But a few sentences later, "Comparatively little can be found in the literature concerning inhibitors . . . The action of these materials has been given comparatively little theoretical study." Some of the inhibitors mentioned in the report are formaldehyde, glue, dextrin, coal distillation products, thiourea derivatives and arsenic compounds. One of their literature references is to a paper by Speller and Chappell. That paper entitled "Inhibitors—Their Behavior in Laboratory and Plant"[11] had been presented at a meeting in Cleveland in 1927. It appeared in the 1927 Transactions of the American Institute of Chemical Engineers.

LOOK for the special "Focus on Plastics for Process Equipment" in the November Technical Topics Section.

More interesting still is another paper presented at the same meeting and appearing in the same volume of the Transactions. The authors of the paper were F. N. Speller of National Tube, E. L. Chappell and R. P. Russell of the Chemical Engineering Department of MIT. The title was "Removal of Rust from Pipe Systems by an Acid Solvent,"[12] and the opening statement read, "The following paper describes the initial application of a new method of removing rust and other substances from pipe systems, namely, the removal of rust from the cold water piping of a large New York office building where the water supply capacity of the system had been seriously diminished by rust accumulation. The method is thought to be equally applicable to the removal of rust from condensers, boilers, heaters and other fabricated systems which would be very expensive to take down and clean by ordinary methods. The removal has been accomplihsed by dissolving the rust in acid rendered inert toward metal by the addition of inhibitors." The chemical cleaning was done in the 35-story Bankers Trust Building in downtown Manhattan, an office building "occupied by tenants of the highest class." So the technology of chemical cleaning was launched by engineering personnel of the highest caliber, as all will agree. The report further describes the careful planning. It emphasizes the necessity for competent supervision. How often have these admonitions been repeated?

Advent of Chemical Cleaning Contractors

By 1940, Dowell, Inc., a subsidiary of The Dow Chemical Company, had been eight years in the business of pumping inhibited acid into oil and gas wells and was venturing into the field of industrial maintenance service. Both services provided a market for millions of gallons of inhibited muriatic acid. During the war years, industrial equipment and manpower was being pushed to capacity and beyond. Any scheme that offered saving in time and manpower was given sympathetic audience.

One of the more serious deterrents to general acceptance of chemical cleaning was, and perhaps still is, concern about corrosion characteristics of the mineral acids even when inhibited. Equally important was the necessity to convince potential users of the safety afforded by the inhibitors. Laboratory corrosion data were an important part of the story, and field experience confirmed that inhibited hydrochloric acid could be handled with relative safety. It became a useful maintenance tool.

Occasionally there were unfortunate experiences. The service company engineer frequently found himself on the defensive. Many agree, however, he and his inhibited acid got the blame for corrosion that they disclosed but did not cause. He did learn there was much more to the corrosion problem than reciting laboratory data obtained by exposing carefully selected metal specimens to inhibited acid solution in controlled laboratory tests.

Laboratory and Field Experience

In several laboratories, scientists continued work on the properties and mechanisms of inhibitors. Several reports are available in CORROSION and Industrial Engineering Chemistry by Mann and Ch'iao,[13] Bried and Winn,[14] Hackerman[15,16] and Nathan.[17,18]

Some more directly concerned with the chemical cleaning service ran tests and wrote reports about behavior of inhibited acids on ferrous and non-ferrous metals and alloys.[19-24] There were observations about the effect of composition, crystal structure, stresses, etc. Questions

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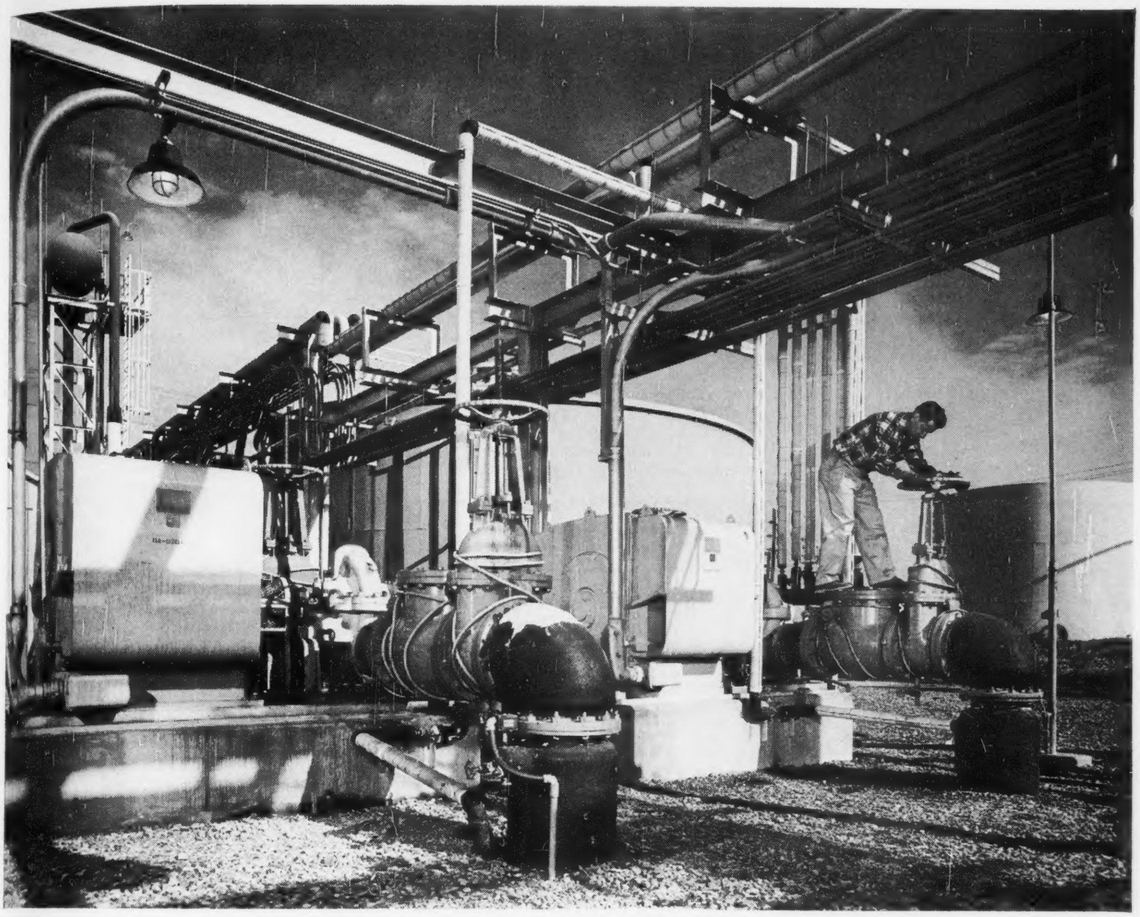

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Chemical Cleaning—

(Continued From Page 20)

arose about the effects of hydrogen in the steel during and after the use of inhibited acids. This subject is discussed by Darken and Smith.[25] Sometimes the phenomenon of crevice or contact corrosion becomes involved in chemical cleaning operations. The general aspects of crevice corrosion were explored by LaQue and co-workers.[26, 27] Though their experimental observations involved sea water rather than acids, the basic concepts apply.

There were contributions to the chemistry of the reactions involved in chemical cleaning and the effect of reaction products on the corrosion rates. Some of the contributors were Alquist;[28] Alquist, Wasco and Robinson;[29] Gatos;[30] Buck and Leidheiser[31] and others. "Ferric ion corrosion" became a common expression. There was little argument about the qualitative explanation but the "quantity" of harm remained obscure and not much was done about it.

When leaves and sheets of re-deposited copper remained in utility boilers after chemical cleaning and subsequently caused tube failures, it was obvious something had to be done.[32] While nearly everyone knew of the redeposition of metallic copper in refinery equipment during chemical cleaning, there was no feeling of urgency about spending money to do anything about it. When hydrogen sulfide is a reaction product, it may increase corrosion rates. Walston and Dravnieks[33] report some observations on this.

Localized corrosion induced by undissolved solids during and after the chemical cleaning is not as well recognized. It is easily demonstrated that mill scale is cathodic to steel in presence of an electrolyte.[34-36] Other solids, including iron sulfides[33] and redeposited copper may be found to have analogous effects. Likewise, undissolved deposits may remain as piles of debris. These piles may defy rinsing and neutralizing and remain soaked with acid solvent or other strong electrolytes. If such debris is not promptly removed, it may produce serious corrosion.

Other papers on chemical cleaning recite other potential hazards. Several such reports are listed,[33, 37, 38] including the paper by Walston and Dravnieks cited above and one by Stander, which appear in CORROSION.

Every discussion of chemical cleaning techniques mentions hydrogen as a reaction product hazard because of the possibility of explosive hydrogen-air mixtures. This hazard is rather easily controlled. Yet, in Power, April, 1954, one finds the article headlined "Hydrogen Bomb in Your Plant."[39] The reaction product, hydrogen sulfide, is well-known to be extremely hazardous. Although it can be handled with reasonable safety through good engineering,

(Continued on Page 24)

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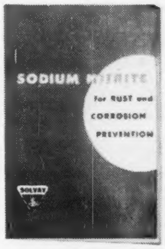

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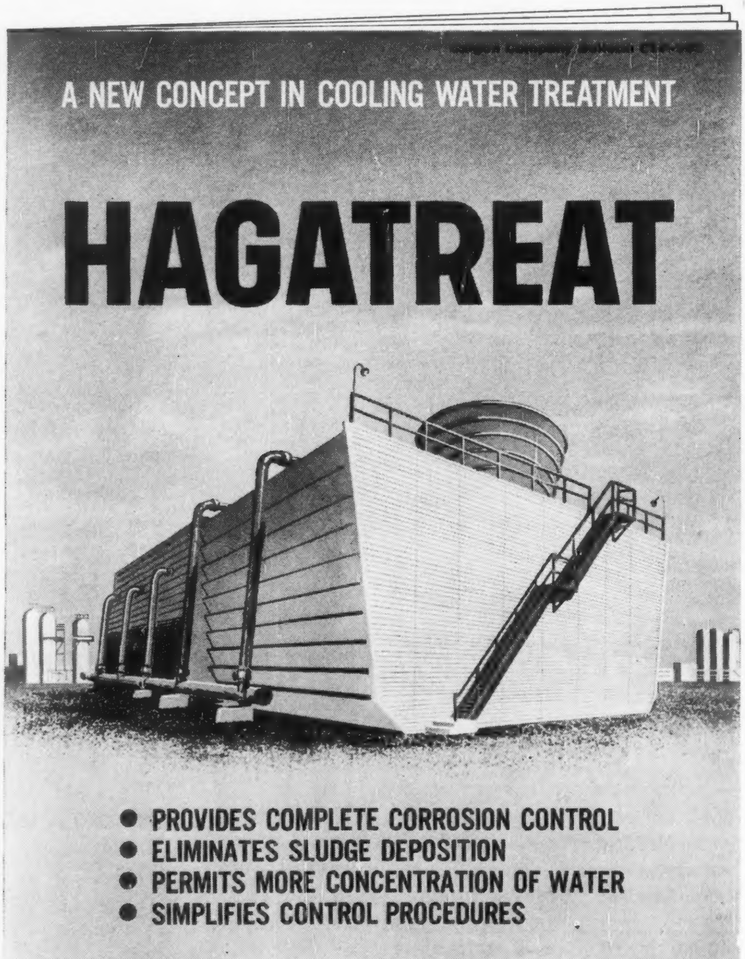

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Chemical Cleaning—

(Continued From Page 22)

several people have lost their lives in accidents involving hydrogen sulfide. The number of near-fatal incidents known to the author is sufficient to justify close attention to this problem.

But, on the more positive side are the many reports, including the one by Speller, Chappell and Russell[12] of successful performance and savings in time and money. Examples of headlines are Acidizing Cuts Costs,[40] Chemical Cleaning Makes Money,[41] Boiler Scale Removal by Chemical Cleaning,[42] Chemical Circulation Methods in Cleaning and Descaling Petroleum Processing Equipment,[43] Old Crude Line Gets a Cleaning[44] and Chemical Cleaning is Cheaper, too.[45]

Buying Contract Service

As the number of chemical cleaning contractors in the field increased, the competitive situation changed and one finds headlines like: Competition Brings Down Your Chemical Cleaning Costs.[46]

As competition in the field increased, the sales approach changed. The chemical cleaning salesman, instead of competing with fear of acids and with use of mechanical cleaning methods, found himself face to face with another chemical cleaning salesman who was saying, "I can do anything you can do and I can do it cheaper." Buyers welcomed this situation and soon many purchasing departments established policies requiring multiple bidding and awarding the contract to the lowest qualified bidder.

Purchasing agents and service salesmen alike struggled with the question of what was being bought and sold. Purchasing of chemical cleaning service involved intangibles. Purchasing agents are familiar with acquiring materials or letting contracts on the basis of specifications or descriptions placed in their hands. The obvious purpose is to describe what is sought, in order that a satisfactory purchase be made from one of several vendors. When both the purchasing agent and the vendors understand precisely what is needed, the need may be filled to the best advantage of the purchaser.

Specification Is Difficult

If the need is for chemical cleaning of plant equipment Units A, B, C and D, how is the transaction usually handled, and what is being purchased? In most cases the handling is simple enough. The purchasing agent says to the service contractors, in effect, "The plant people contemplate chemical cleaning of Units A, B, C and D. What is your price?"

Price for what? For examining the equipment to obtain samples, ascertain materials of construction and observe the physical condition of the equipment? For analysing samples to determine what reaction products may be encountered that can corrode the equipment or kill someone? For time to plan and engineer the service so it can be done safely? For adequate supervision, so chemical analyses may be made on the job, and so supervisors and crews are not worked to exhaustion? For submitting engineering reports describing procedures used and evaluating results? Or for some truckloads of inhibited acid to be pumped into the equipment Units A, B, C and D?

If a service contractor is asked for a price to clean Units A, B, C and D, what is expected of him? Is he motivated to spend his time and money doing things that are not specifically called for, knowing that if he does he can't afford to meet the competitor's price? These considerations often lead to shortcuts around safeguards and to gambling with expensive equipment and with people's lives. Potential hazards involved in chemical cleaning demand that every possible precaution be taken. Why then in some cases are even the most elementary precautions neglected? Because of indifference to the potential hazards? No. Chances are taken because the motivation is inadequate.

Service contractors themselves did much to create this situation. For years, it was a common concept that a customer bought a clean unit, and how it was cleaned was none of his concern. Contractors resented customers submitting specifications or requiring detailed plans describing what was to be done and how. They resented the customer poking into their secrets or getting the idea the method was so simple he could do it himself. Also, many feared he might reveal plans and ideas to competitors. No report was provided unless he insisted. Unit prices or itemized price breakdowns would not be included in the invoice so he could tell what he was paying for. While some of these attitudes have changed, the basic difficulty of lack of definition of what is being purchased remains.

Another undesirable aspect of the present buying procedure is: How can three or more competing service contractors perform the pre-cleaning phases of investigating and planning without putting the customer's people to the inconvenience of going over the ground three or more times? Plant supervisors find this procedure annoying and time-consuming.

Is the "Professional" Needed?

Also, another question is part of the problem. Is the service contractor to be considered a professional, an expert in a highly specialized field of chemical engineering, a specialist in solving maintenance problems through chemistry? Or, is he a truck owner who is in the acid vending business?

Many contractors want to be regarded as professionals, interested in solving maintenance problems and in the proper care of equipment, much as a doctor is interested in solving health problems and in the well-being of his patients. If industry needs professionals, the question arises: "Do present policies allow a contractor to develop a continuity of interest in, or knowledge of, the problems in a given plant?" Are bids from three local doctors sought in time of sickness? If the chemical cleaning contractor is to be a plant maintenance "doctor" with a professional interest in a plant's problems, he can't be expected to fight for every job, and intermittently be allowed to care for the "patient." Present methods tend to force contractors to be vendors of acid, with the job going to the vendor who sells acid at the lowest price. When this happens, who is responsible for the chemistry, the engineering, the corrosion and the safety aspects of the operation?

What is known about controlling corrosion is less important than what is done about it. What contractors do depends on what they can get pair for. In a competitive market getting paid for things

(Continued on Page 26)

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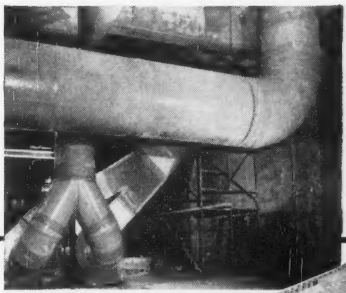

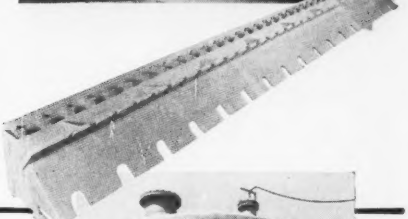

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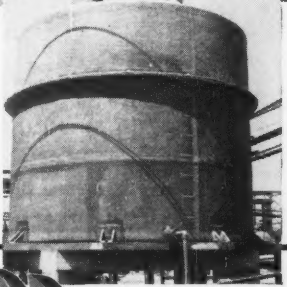

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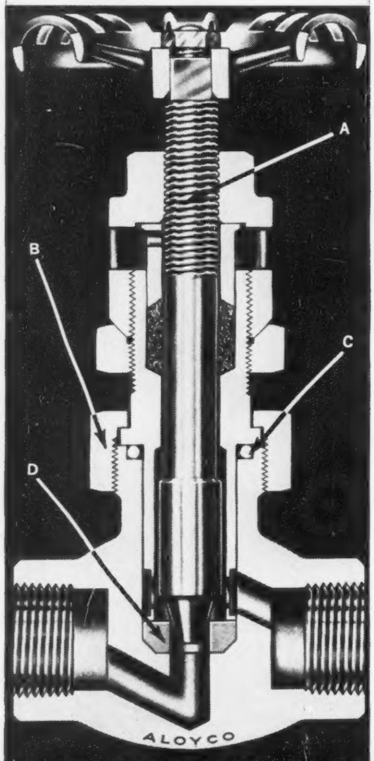

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Chemical Cleaning—

(Continued From Page 24)

not specified in the purchase transaction is difficult. Present methods of purchasing contract service need to be re-examined critically and objectively.

Chemical cleaning can become a more useful maintenance tool than it has been. If chemical cleaning can save time and money in plant maintenance, management will be motivated to explore further applications. Service contractors will continue to serve a useful purpose. Because muriatic acid will continue to be the cheapest and most reactive acid solvent for dissolving inorganic scale and corrosion products and because of the properties of muriatic acid, most plant operators prefer to leave its handling to properly equipped and experienced contractors.

Other Cleaners Are Available

Many chemicals other than muriatic acid have potentials in maintenance work with less corrosion hazard. Most cost more per pound. Some are now packaged and used primarily on a do-it-yourself basis because they are relatively safe and easy to handle. For obvious economic reasons, service contractors, with substantial investments in trucks and acid storage and handling equipment, have not explored new chemicals extensively. Several chemical companies manufacturing products which have maintenance applications are calling attention to possible uses in advertisements and trade magazine articles. Examples are citric acid,[47] sulfamic acid,[48] and chelating agents.[49] Vendors are doing some development work with their products and furnishing technical service to purchasers as part of sales promotion efforts. These and many other materials offer interesting chemical properties and maintenance possibilities.

Conclusion

This article is not intended to give a packaged answer to the problem of controlling corrosion during chemical cleaning. But for those who believe the problem exists, it may help them to analyse the problem and to explore some aspects which heretofore have not been discussed.

What can individuals interested in controlling corrosion do? When a maintenance problem arises, why not get together with responsible people from the several departments involved: Operations, maintenance, engineering, purchasing, materials, inspection, corrosion control and management? A stimulating discussion, with each describing how he sees the problem very likely will produce constructive suggestions. Every service contractor who sincerely tries to give good service will cooperate fully to improve the present unsatisfactory situation. The writer believes that few contractors give so much of themselves personally for so little reward as do the chemical cleaning people. Why do they? Because the work is challenging and intensely interesting to one who likes to solve problems and to help others solve them.

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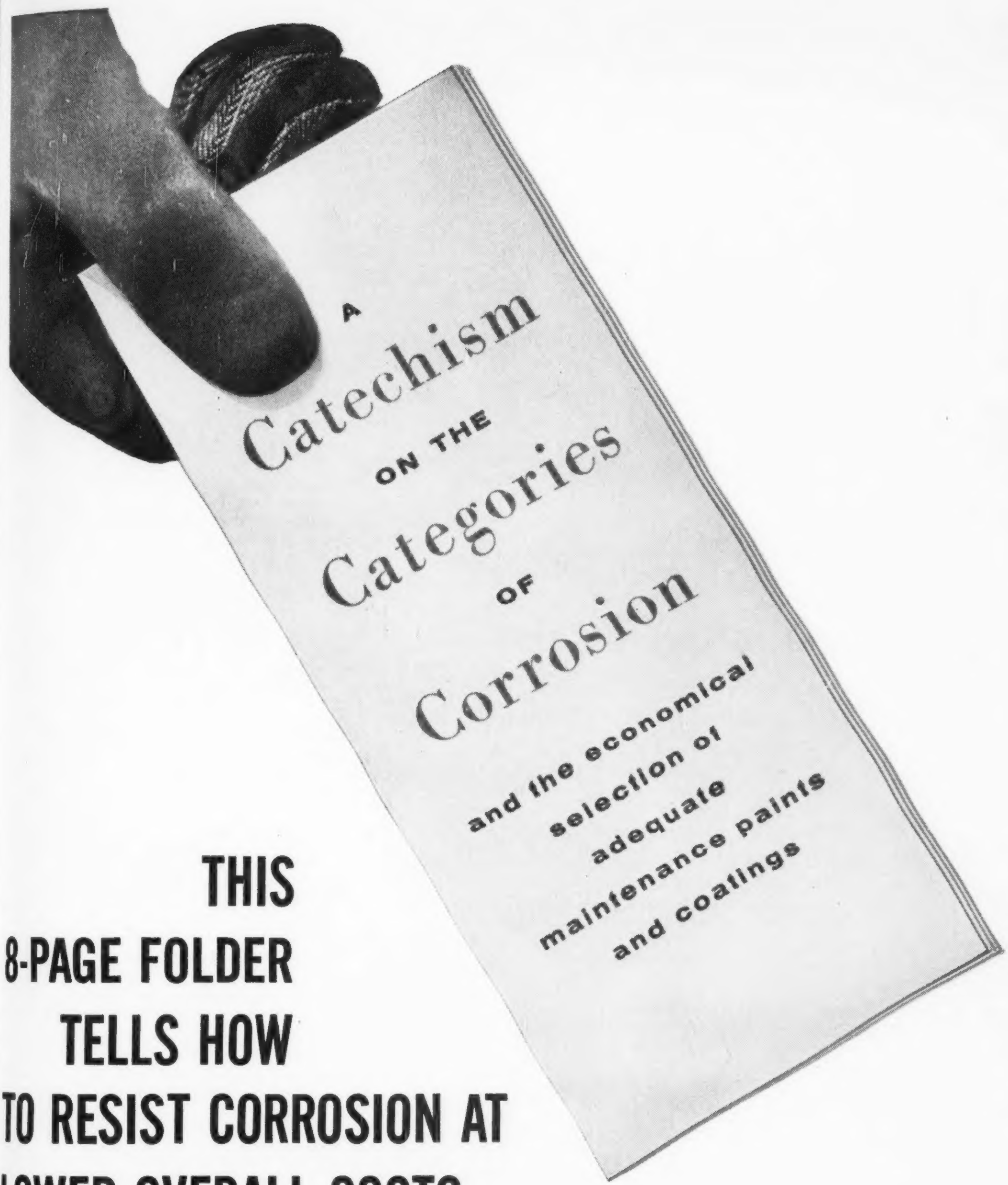
EDITOR'S NOTE: See also "Chemical Cleaning of Equipment in Refineries and Petrochemical Plants" by Lambert N. Klinge and Johan Silman. *Corrosion*, **16**, No. 1, 9t-18t. (1960) Jan. (26t References).

Focus on Plastics for Process Equipment

The November issue's Technical Topics Section will be devoted to discussing the use of plastics for process equipment. Other interesting articles on plastics will be featured in that issue also.



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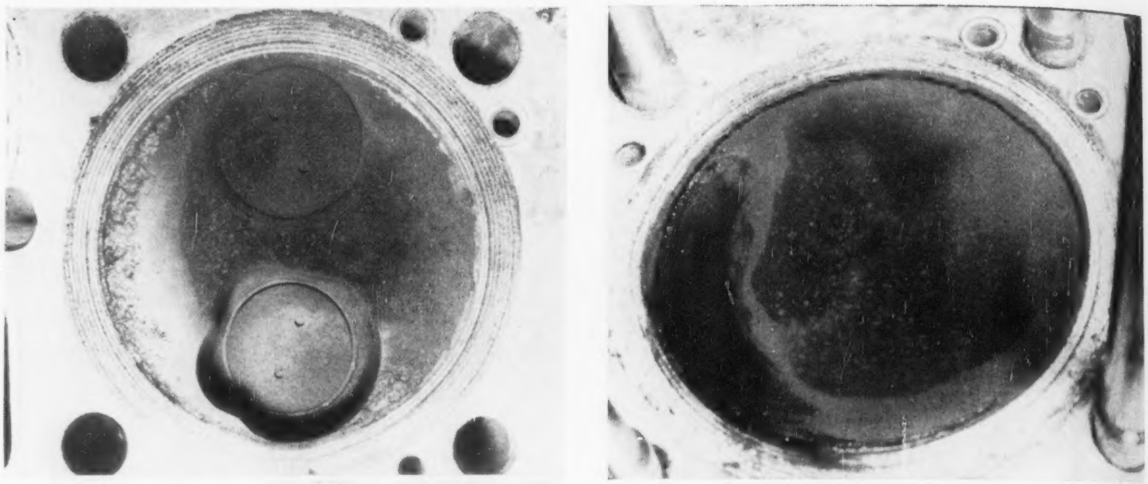

Figure 1—Good condition of valves (left) and piston head (right) after 25-hour test of single cylinder, 4-cycle Diesel engine burning Diesel oil and powdered coal at an oil-to-coal ratio of 1 to 1.

Lubricating Oil Contamination Drawback in Coal Burning Diesel★

H. P. Marshall and Carl Shelton, Jr.

Virginia Polytechnic Institute
Blacksburg, Virginia

Abstract

Investigation is described to determine whether or not pulverized coal with low ash content will burn in the cylinder of a Diesel engine and what effects it would have on engine performance, operation and wear. 7.1

CONTAMINATION OF lubricating oil with unburned coal proved the principal limiting factor in operating a Diesel engine on a mixture of Diesel fuel and oil at the Virginia Engineering Experiment Station, Virginia Polytechnic Institute, Blacksburg, Va. Tests were made with a 4-cycle, single cylinder, poppet valve engine.

Tests were conducted with coal from two sources which had been pulverized to contain approximately equal amounts of 100, 150, 200 and 270 mesh sizes. Both coals were selected for their low ash, low sulfur content. Mixtures of coal and oil varied from one to 10 in initial tests to 1 to 1 in that portion of a 100-hour test which was completed. Coal was fed into the oil by means of a patented feeder.

Thirteen hours after the start of a 100-hour test an exhaust valve push rod broke and the engine was shut down. It was disassembled and an examination showed the coal dust in the lubricating oil had worn away all Babbitt metal from the connecting rod bearing, that the piston was seizing on the thrust side and the condition of the rings was very poor. The cylinder liner had a few score marks due to action of small pieces of the chrome face of the top piston ring which had broken away.

After reassembly with a new piston, piston rod, cylinder liner and new rings, another test using coal was ended after 7 hours when the engine would not start due to loss of compression. On disassembly the piston rings were found to be stuck and the piston badly scored. This was believed to be the result of poor lubrication caused by contamination of the lubricating oil.

The engine was reassembled with a new piston and ring; the oil scraper ring was omitted from the piston skirt to get more oil to the top of the piston. A 25-hour test at a 1 to 1 ratio of oil to coal dust was run, the last 22 hours being continuous. Oil pressure dropped to 10 psi because of clogging.

The head, valves and exhaust system were found to be in good condition and the engine burned without producing excessive smoke. See Figure 1.

Conclusions reached were: Fuel oil consumption was reduced from 7.07 lb/hr to 5.30 lb/hr by introduction of 5.6 lb/hr coal dust. Brake thermal efficiency was reduced from 18.2 percent on oil to 13.4 percent on a coal and oil mixture running at 10 hp at 1750 rpm.

Cost of fuel is reduced about 1.25 cents an hour when operating at 10 hp and 170 rpm and when using coal-and-oil mixture compared to Diesel oil only with oil at $16 per 100 gal and coal at $10 a ton.

Researchers recommended the following procedures to get longest life for a coal burning piston engine: Overlapping compression rings; high capacity full flow oil filtering; large capacity crank case; no oil scraper rings below piston pin and a feeder to inject dust into the cylinder just before ignition. Further tests were indicated to determine optimum coal particle size.

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(In February, 1956, Page 113 of CORROSION reported on operation of a Diesel engine using gasoline and coal dust by R. E. Harvey, Roanoake, Va. The information was obtained from the Mineral Industries Journal, a publication of VPI at Blacksburg, Va.)

Focus on Plastics in Process Equipment

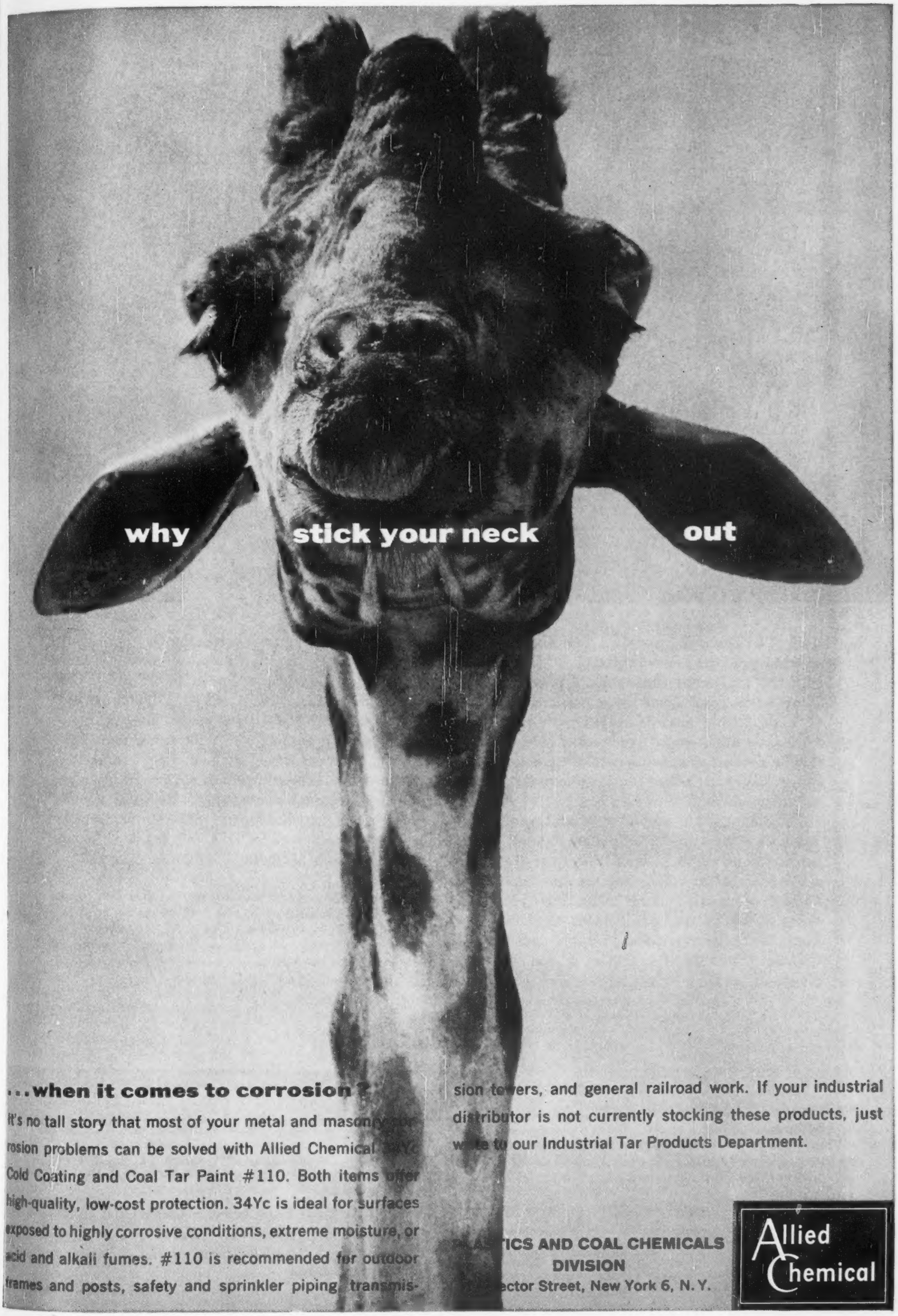
Applications of plastic materials for process equipment will be discussed in the Technical Topics Section for November.

Technical Topics Included in Index

Technical Topics will be included in CORROSION's annual index published in the December issue. The Topics will be cross-referenced in the alphabetical subject and author index.

Persons who customarily extract Technical Section pages from each issue for binding are reminded that the Technical Topics pages should be extracted also for a more complete reference to technical information published in CORROSION.

★ Abridged from an Article "The Coal Burning Piston Engine" published in the Bulletin of the Virginia Polytechnic Institute, Vol. 53, No. 1, November, 1959.



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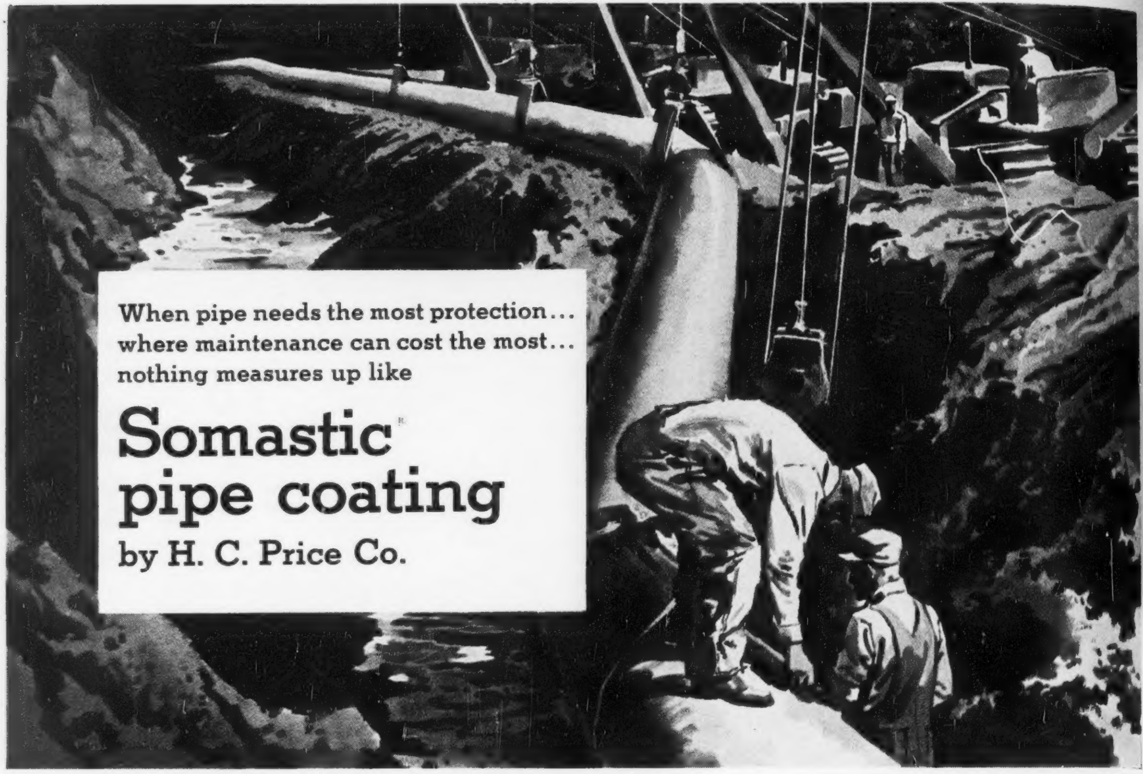

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How about the economics? Today, the H. C. Price Co. Pipe Coating Division offers SOMASTIC® pipe coating at prices sharply competitive with enamel wraps or other coatings. Low initial cost combines with predictable low maintenance costs for the most favorable pipe coating economics available. Because of its greater weight, SOMASTIC® offers considerable savings where weight is a factor, such as in marine or swamp installations.

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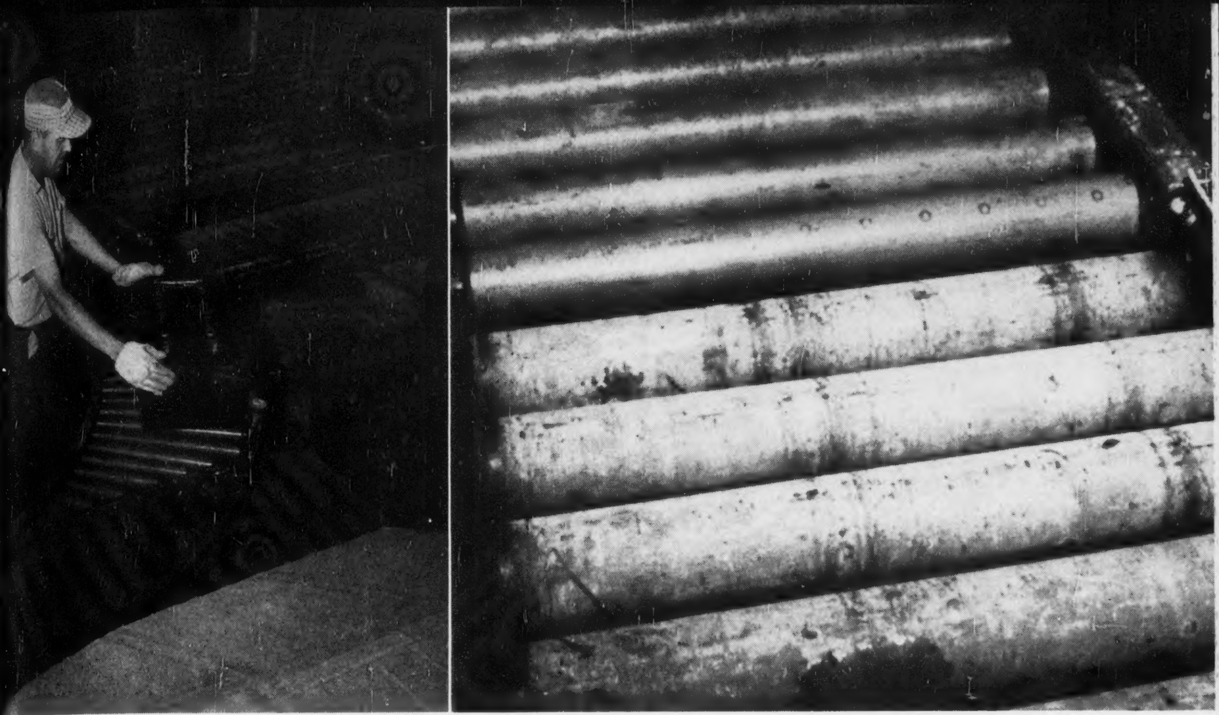
Cable Address: HCPCO



PVC ROLLERS AND SHAFTS were used for this conveyor network in a battery plant to eliminate corrosion losses caused by sulfuric acid drippings. At the right is shown the contrast of conditions between the PVC rollers at the top and the four metal rollers at the bottom. The PVC rollers have withstood one year's service; the metal rollers show badly corroded areas after only six months' service.

PVC Rollers in Conveyor System Resist Battery Acid Corrosion

A conveyor network with polyvinyl chloride rollers has eliminated sulfuric acid corrosion losses and has replaced push-tables in a storage battery plant's production line.

After one year's service in the severely corrosive exposure to sulfuric acid, the PVC rollers showed no damage, but an assembly of metal rollers installed for test purposes beside the PVC rollers showed badly corroded areas from the sulfuric acid drippings, as shown in the photographs above.

PVC sheets also are used as guide separators between lines of batteries in sections of the conveyor where three independently moving lines require three short rollers operating on one long shaft.

Because the shafts, bushings and rollers are subjected to corrosion from the battery acid drippings, the complete roller assembly was fabricated of PVC. Rollers were made of 1½-inch PVC pipe. Plastic bushings cemented inside each roller end accommodate the shafts which are made from ¼-inch PVC pipe used for the shaft.

This installation at the Scranton Battery Company in Scranton, Pa., has verified previous tests made on the PVC roller system. The Scranton conveyor has withstood one year's service with no corrosion damage. A 50-foot test section of metal rollers was badly corroded and deteriorated after only six months' service.

Before the Scranton plant installation was made, a PVC roller assembly was tested at temperatures of 72, 120 and 140 F at operational loads of 80 and 120 pounds. PVC roller deflection was slight. At heavier center point loads of 380 to 400 pounds, roller deflection was about 1.5 inches, with immediate spring-back to original form after the load was removed. Because the load at the battery plant was spread over a series of rollers, deflection at the heavier loadings was negligible.

Designed by Scranton Battery, the conveyor network uses over 18,600 feet of PVC pipe for rollers and shafts. Pipe used was Type I, Schedule 40 and 80 supplied by A. M. Byers Company, Clark Bldg., Pittsburgh, Pa.

Anodized Aluminum Withstands Fading and Corrosion Exposures

Outdoor exposure tests for over three years in various parts of the United States have shown no perceptible fading or corrosion on test panels of anodized aluminum designed for architectural applications.

Three natural environmental test sites were used (1) Battelle Memorial Institute's North Florida Research Station near Daytona Beach, Florida, for a coastal marine exposure, (2) an industrial exposure on the property of a metal processing plant and (3) desert exposure conducted by Desert Sunshine Exposure Test Company of Phoenix, Arizona.

At the marine site, the aluminum panels faced the ocean at a distance of 350 feet from the water. Performance of the panels at this test site has been found by other tests to be comparable to that of aluminum at the 80-foot station on the beach at Kure Beach, N. C.

At the severe industrial site, the panels faced south and were downwind from the flow of carbon dust, chlorine and other contaminants coming from the furnace section of a metal fabricating plant.

The panels were anodized by a new process caller Kalcolor, developed by Kaiser Aluminum & Chemical Corporation, 300 Lakeside Drive, Oakland 12, Cal. Color tones are created during the process through conversion of alloying elements within the metal itself. Kaiser is producing this architectural aluminum alloy as extrusions and sheet for use in commercial construction.

Accelerated tests also conducted on this anodized aluminum showed no perceptible fading or corrosion. These included 15,000-hour salt spray exposure, 7000-hour water fog exposure and high intensity ultra violet ray exposure for over three years. The latter test is considered by Kaiser engineers to be equivalent to about 25 years' exposure to sunlight.

Miniature TV Camera

A television camera and transmitter that will fit into the 4½-inch diameter nose cone of the Arcas rocket is to be built under a contract from the U. S. Navy.

BOOK NEWS

Making Better Plastic Welds. By Donald W. Thomas. 56 pages, 6 x 9, paper. 1960. Laramy Products Co., Beechwood St. at Route 3A, Cohasset, Mass. Per copy, $1.

An illustrated manual on how to make welds in plastic. Chapters cover history and development of plastics, plastic welding equipment, welding plastics, tacking, hand welding, semi-automatic speed welding, special instructions applicable to specific materials.

Inspection, testing and evaluation of welds; thermoplastics and lining materials, physical characteristics of some commonly used plastics and training exercises.

Metallic Corrosion Inhibitors. By I. N. Putilova, S. A. Balezin and V. P. Barannik. 196 pages, 5½ x 8½, cloth. 1960. The Pergamon Press, 122 East 55th St., New York 22, N. Y. Per copy, $10.

A translation from the Russian text by G. Rynback, edited by E. Bishop. Contents include introduction and brief historical survey, classification of inhibitors and laws governing them.

Concepts of the mechanism of protective action, inhibitors in aqueous solutions of acids and alkalis; in water and aqueous solutions of salts; atmospheric corrosion inhibitors and inhibitors for non-aqueous liquid media.

Appendices cover pickling procedure, removal of boiler scale with hydrochloric acid; metals protection against atmosphere using inhibitor-impregnated paper. There is an index of inhibitors and related substances keyed to the text.

Most of the references are to Russian or European literature.

Corrosion. 10 Year Bibliography. SB-401 40 pages, 7⅞ x 10¼ inches, self-cover. U. Dept. of Commerce. Office of Technical Services, Washington 25, D. C. Per copy, 10 cents.

A bibliography of titles of reports listed in U. S. Government Research Reports and Technical Translations. Some sections include abstracts from 1948-59 inclusive. Information necessary for ordering copies is given under each title.

Reports are grouped under the following headings: Corrosion resistant coatings, AEC Reports on Corrosion Resistant Coatings, Translations on Corrosion Resistant Coatings; Corrosion Resistant Materials, AEC Reports on Corrosion Resistant Materials; Stress Corrosion, AEC Reports on Stress Corrosion; Corrosion Inhibitors, AEC Reports on Corrosion Inhibitors; Corrosion Tests and Testing Equipment, AEC Reports on Corrosion Tests and Testing Equipment; Corrosion General, AEC Reports on Corrosion, General; Translations on Corrosion, General.

An appendix gives sources of translations and locations of depository libraries for translations.

The Surface Chemistry of Metals and Semi-Conductors. Harry C. Gatos, editor. 526 pages, 5¾ x 9 inches. 1960. John Wiley & Sons, 440 Fourth Ave., New York 16, N. Y. Per copy, $12.50.

A symposium sponsored by the Office of Naval Research and The Electrochemical Society, Inc. at Columbus, Ohio, October 19-21, 1959.

Material is divided into: Chemistry and physics of surfaces, imperfections and surface behavior, electrode behavior of metals and semi-conductors, surface reactions in liquid media and surface reactions in gaseous media. The 22 papers are accompanied by discussions. The book is liberally illustrated, contains many diagrams illustrating points in the text and graphed data.

The symposium was held for the purpose of providing a medium for the exchange of theory and technology between the fields of metal surfaces and semiconductor surfaces. Technical progress in processes involving reactions at surfaces, especially those involving semi-conductors has been at an accelerating rate in recent years. At the same time substantial progress has been made in understanding of the theoretical problems associated with surface states, especially abroad.

All of the papers are thoroughly referenced. An alphabetical subject index is included.

Tables for Identification of Organic Compounds. Charles D. Hodgman, editor. 241 pages, 6¼ x 9¼ inches, cloth. 1960. Chemical Rubber Publishing Co., 2310 Superior Ave. N. E., Cleveland 14, Ohio. Per copy, $7.

Tabulated data are given on the characteristics of 4380 organic parent compounds. The compounds are arranged in 17 classes: Alcohols, aldehydes, alkyl and aryl halides, amines, amino acids, aromatic hydrocarbons, carbohydrates.

Carboxylic acid anhydrides, halides and acids; ethers, ketones nitriles, nitro compounds, phenols, quinones and sulfonic acids.

Data are arranged according to melting point, crystal color and solvent from which crystallized.

Also included are miscibility of organic solvent pairs, surface tension of various liquids, emergent stem correction for liquid-in-glass thermometers, correction of boiling points to standard pressure, molecular elevation of the boiling point, molecular depression of the freezing point, periodic chart of the elements and atomic weights.

European Federation of Corrosion. 1958 Yearbook. 135 pages, 8¼ x 11½ inches, paper, typescript. January 1960. Dechema, Frankfurt (Main), Germany. Availability not indicated.

Contains reports of the European Federation of Corrosion for 1958 in German, French and English; reports of the member societies of the federation in the languages of the respective members in most instances and a list of research institutions concerned with corrosion problems.

The federation's 56 members from 14 countries are listed as is membership of committees, agendas of meetings, elections, letters sent to members.

Each of the member organizations reports its officials, objectives, accomplishments during the year, including publications and meetings. Names of books and periodicals are given.

FOCUS ON PLASTICS IN PROCESS EQUIPMENT

Five articles on plastic applications for process equipment will be featured in the Technical Topics for November as part of that issue's special "Focus on Plastics in Process Equipment." Titles of these articles are given below.

Another feature of the "Focus on Plastics" in the November issue will be publication of a report of NACE Task Group T-4B-5 on Non-Metallic Sheaths and Coatings. The report is entitled "Practices and Experience With Protective Jackets for Outside Plant Lead and Aluminum Sheathed Cable."

Articles to be published in the November issue's Record and Report Section also will include information on plastics used for corrosion control. These articles will deal with vinyl coated exhaust stacks, reinforced plastic pipe for handling corrosive wastes, a new polyvinyl dichloride that can be used in industrial hot-acid piping and reinforced polyester panels used to prevent corrosion of industrial building sidings.

Technical Topics for November are as follows:

Some Results from Elevated Temperature Testing of Polyester Castings and Laminates, by S. S. Feuer and A. F. Torres.

Laboratory Testing of Spay Applied Lining Materials, by R. S. Foster.

Design Considerations for Applying Reinforced Plastics in Corrosive Environments of the Process Industry, by Fred W. Arndt.

Case Histories Indicate Tetrafluoroethylene Lined Pipe Has Lower Installation Cost Than Other High Temperature Piping, by T. R. Thierry.

Characteristics, Testing and Some Design Considerations Applicable to Glass-Reinforced Plastic Pipe, by R. M. Levy.

New Technique Described For Complex Data Analysis

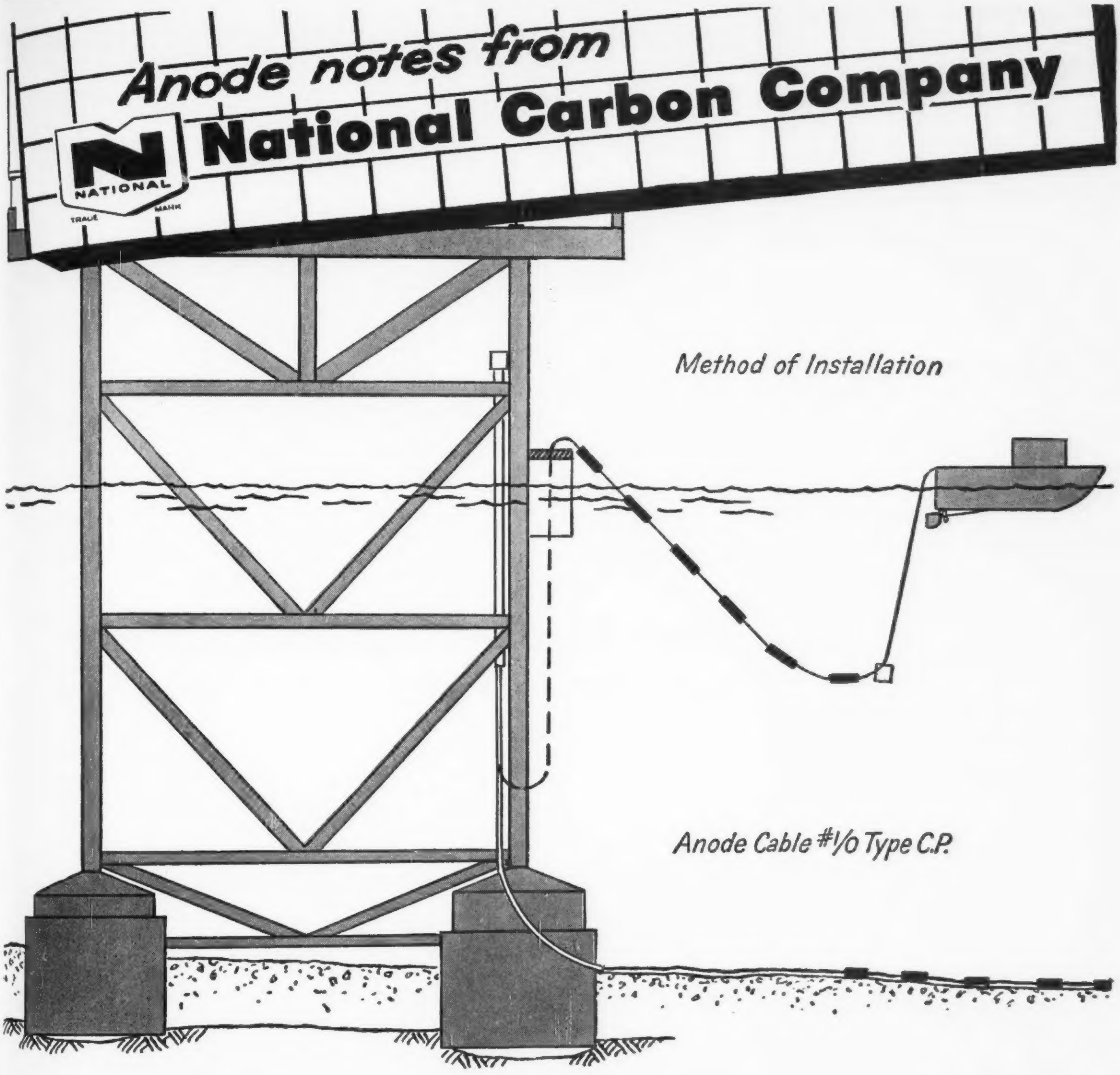
Edgegraphing, a new technique for hand analysis of complex engineering data in 10, 20 or more variables, is discussed in technical literature available from Statistical Engineering Institute, 8 Fuller Road, Wellesley Hills 81, Mass.

Edgegraphing is described as a practical method for mass analysis of complex data. Electronic computers usually available to engineers have been inadequate for this job from the viewpoints of calculation volume, administrative convenience and time required.

European Corrosion

The 15th meeting of the European Federation of Corrosion is scheduled during the 1961 European Congress of Chemical Engineering, June 9-17, 1961, to be held in Frankfurt am Main.

Invitation brochures translated into English, French, German, Italian and Spanish can be obtained by writing Dechema, Frankfurt am Main 7, Postfach.



PROTECTION OF A $4,750,000 OFFSHORE DRILLING RIG

Corrosion engineers of a large oil company decided to use impressed current cathodic protection on the underwater foundation of an offshore drilling rig.

Six strings of 10 "National" NA Graphite Type QA Anodes* were used to provide a distributed anode bed. They were assembled on 1/0 C.P. cable at fifteen foot spacings. Anode strings were placed radially around the platform on the sea bottom with the first anode approximately 200 feet from the platform base. The anode strings are held in place by 12"x12"x16" concrete anchor blocks at the end of each string.

"National" NA Graphite Anodes were selected because of proved long anode life (about 0.1 lbs./amp. year consumption in free moving salt water) and low initial cost.

*Anodes were sold by The Vanode Company, Pasadena, California

"National", "N" and Shield Device, and "Union Carbide" are registered trade-marks for products of

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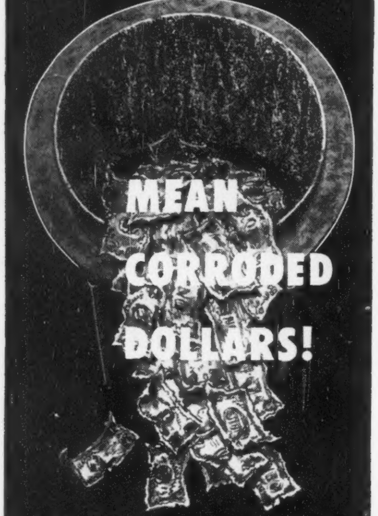
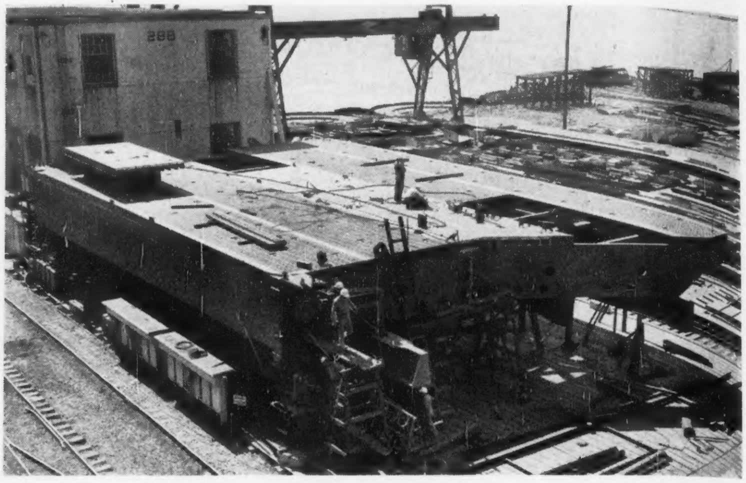




FOUR ALUMINUM ELEVATORS, measuring 52 feet wide and 85 feet long and each weighing 105 tons, will be installed on the USS Enterprise, the first nuclear powered aircraft carrier. The elevators will be used to lift advanced jet aircraft from the hanger to the 252-foot wide flight deck.

First Nuclear Aircraft Carrier To Have Aluminum Elevators

Huge elevators almost large enough to be highway bridges are being fabricated of aluminum for use on the USS Enterprise, the first nuclear powered aircraft carrier. Measuring 52 feet wide and 85 feet long, the elevators are all-welded construction, fabricated of aluminum extrusions and plate. One of the elevators is shown in the accompanying photograph.

Four of these elevators will be installed on the Enterprise: three to starboard and one to port. Each weighs 105 tons, which is a 30-ton saving over high tensile steel. Lighter, less bulky machinery thus can be used to operate the elevators which will lift aircraft from the hangars below decks to the 252-foot wide flight deck.

Each of the four elevators was built around three load carrying structural systems, with each system distinguished by the size of its main members which are aluminum I-beams.

These beams were fabricated of aluminum plate that ranged up to 2 inches in thickness. Top surface of each elevator is a grating structure made by welding short lengths of T-shaped extrusions, spaced 1½ inches apart, crosswise between 30-foot I-beams. This system rests on a secondary structure built of 16-inch deep I-beams. Entire weight of the elevator is carried by 10-foot deep beams that form the main supporting structure.

Launching and christening of the Enterprise is scheduled for this month. The 86,000-ton ship's eight nuclear reactors are expected to operate five years on the first charge of fuel. The ship is designed to operate at sustained speeds of more than 30 knots.

Aluminum extrusions and plate for the elevators were supplied by Aluminum Company of America, Pittsburgh 19, Pa.

1960 Corrosion Show Color Slide-Talk

A show consisting of 108 color slides has been prepared showing some of the exhibits at the March 15-17 Dallas exhibition. This 1960 Corrosion Show color slide presentation will be accompanied by a commentary describing the exhibits and many of the items displayed.

NACE Section program chairmen who are interested in using this in one of their programs may make bookings by writing to G. A. Rolak, 1061 M & M Bldg., Houston 2 Texas.

The show gives members who were unable to attend the conference an opportunity to see some of the exhibits at what many have said was the best Corrosion Show held so far.

Plastics Society Offers Activity Group Brochure

A new brochure entitled "Professional Activity Groups—Your Opportunity to Grow Professionally in Plastics" is available from the Society of Plastics Engineers, 65 Prospect St., Stamford, Conn. The brochure outlines the function, advantages, organization and operation of the activity groups in general and gives the scope and summary of activities of each of the current 15 groups.

The Plastics Society will begin publication of a new quarterly scientific journal entitled "SPE Transaction" in January, 1961. It will contain articles on basic polymer theory, science and engineering. The Journal will contain no advertising and will be available to members and non-members of the society on a subscription basis. The Journal is being designed to supplement the "SPE Journal," the official publication of the society.

Why metals corrode...and how you can prevent it

The basic cause of corrosion is the instability of metals in their refined state. Metals tend to revert to their natural states through the processes of corrosion. For example, when you analyze rust, you will find it is iron oxide. When you analyze natural iron ore, you find it, too, is iron oxide. Six forms of corrosion which can attack the equipment you design are:

1. General tarnishing or rusting with occasional perforations in highly affected areas.
2. Highly localized attack by pitting.
3. Cracking induced by a combination of stress and corrosion.
4. Corrosion confined to crevices, under gaskets, or washers, or in sockets.
5. Corrosion of one of an alloy's constituents leaving a weak residue.
6. Corrosion near the junction of two different metals.

In all of the six forms of corrosion mentioned above, corrosion has the same basic mechanism. It's similar to the electrochemical action in a dry cell.

The electrolyte in the dry cell corresponds to the corrosive media, which may be anything from the moisture in the air to the strongest alkali or acid.

The plates of the battery correspond to the metal involved in corrosion.

A potential difference between these metals or different areas on the same metal causes electricity to flow between them through the electrolyte and a metallic bridge or contact that completes the circuit.

At the anode, a destructive alteration or eating away of metal occurs when the positively charged atoms of metal detach from the solid surface and enter the solution as ions.

The corresponding negative charges, in the form of electrons, travel through the metal, through the metallic bridge, to the cathode.

Briefly then, for corrosion to occur, there must first be a difference in potential between the metals or areas on the same piece of metal so that electricity will flow between them. Next, a release of electrons at the anode and a formation of metal ions through disintegration of metal at the anode. At the cathode, there must be a simultaneous acceptance of electrons. Action at the anode cannot go on alone, nor can action at the cathode.

CONTROLLING CORROSION

When corrosion occurs because of the differences in electrical potential of dissimilar metals, it is known as galvanic action. Differences in potential from point to point on a single metal surface causes corrosion known as local action.

When you plan against galvanic corrosion it is essential to know which metal in the couple will suffer accelerated corrosion . . . will act as the anode in the corrosion reaction.

The galvanic series table shown below can supply this information. In any couple, the metal near the top of this series will be the anode and suffer accelerated corrosion in a galvanic couple. The one nearer the bottom will be the cathode and remain free from attack or may corrode at a much slower rate.

GALVANIC SERIES TABLE

Magnesium
Magnesium alloys
•
Zinc
•
Aluminum 25
•
Cadmium
•
Aluminum 17ST
•
Steel or Iron, Cast Iron
•
Chromium-iron (active)
•
Ni-Resist
•
18-8 Stainless (active)
18-8-3 Stainless (active)
•
Lead-tin solders
Lead, Tin
•
Nickel (active)
Inconel* (active)
•
Brasses, Copper, Bronzes
Copper-nickel alloys, Monel *
•
Silver solder
•
Nickel (passive)
Inconel (passive)
•
Chromium-iron (passive)
18-8 Stainless (passive)
18-8-3 Stainless (passive)
•
Silver
•
Graphite, Gold, Platinum

HOW TO USE THE CHART

Notice how the metals are grouped in the galvanic series table. Any metal in one group can be safely used with any other metal in the same group. However, when you start mixing metals from different groups, you may run into serious galvanic corrosion of the metal higher on the list. And the further apart these metals are listed, the worse this corrosion may be.

But, if you have to mix metals, pay particular attention to the electrical contact between them. Eliminate any metallic bridges or contacts of metal to metal that will permit the flow of electrons through them. You can do this by separating the metals physically, or by using insulation or protective coatings. Another factor is the relative areas of the metals in contact with each other. Parts having the smaller area should be of a metal with a lower listing on the galvanic series table than the metal used for the larger area.

When you plan against local action, remember that the corrosion process is galvanic: Electrons move from one point in the metal to another. One of the easiest ways to prevent local action is to use a metal with little or no impurity. When alloys are involved, make sure the constituents are closely listed in the galvanic series table. Local action may also be stopped by the use of protective coatings, which shield the metal from the corrosive media. Environment must also be considered, for its nature may be an important factor in either promoting or restricting corrosion.

TECHNICAL ASSISTANCE

As you can see, many factors are involved in both local and galvanic action. That's why it's best to bring your metal problem to Inco's Corrosion Engineering Service. Available data will be furnished wherever possible . . . tests will be made where needed. Inco's Corrosion Engineering Service will be glad to apply principles of corrosion control to your specific problem.

LITERATURE

The publications listed below will provide more detailed information on how you can combat corrosion by using nickel-containing metals.

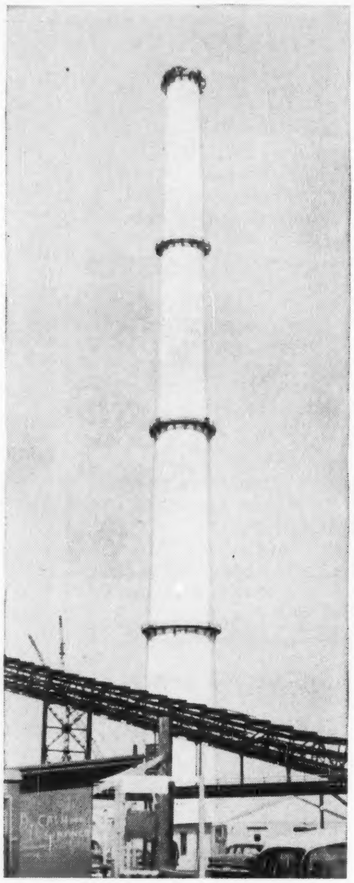
Publication Number	Name
A232 . . .	Corrosion Problems in Nuclear Reactor Power Stations
A59	Factors of Importance in the Atmospheric Corrosion Testing of Low-Alloy Steels
A62	A Theory of the Mechanism of Rusting of Low-Alloy Steel in the Atmosphere
A137 . . .	Corrosion by Some Organic Acids and Related Compounds
A144 . . .	Some Observations of the Potentials of Stainless Steels in Flowing Sea Water

A complete list of the 187 Inco publications and technical bulletins on nickel-containing metals can be obtained by writing for "List A", to:

*Registered trademark

The INTERNATIONAL NICKEL COMPANY, Inc.
67 Wall Street INCO New York 5, N.Y.

See how FOAMSIL®



PROBLEM: REFRACTORINESS

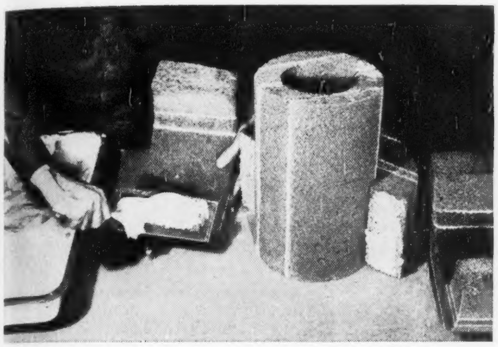
At Consolidated Edison's Arthur Kill Station, FOAMSIL protects concrete stacks from hot gases and fast deterioration. The life expectancy of the 500-ft. stacks is increased because the 99 per cent pure fused silica insulation stays impervious to acids and takes *continuous* operation up to 2000°F. (FOAMSIL withstands cyclic temperatures ranging from —450°F to +1600°F.) Joints are sealed with Pennsalt Chemical's Synar silica cement to insure uniform insulation value.

PROBLEM: THERMAL SHOCK

The unique refractory properties of FOAMSIL eliminate the problem of insulation cracking due to thermal shock. This solved a problem for Silverstein's Bakery, Toronto, where chimney walls were overheating. Though the incinerator was not used continually, it was called on to withstand flash temperatures as high as 1000°F and lower temperatures higher up the stack. The old insulation was ripped out and FOAMSIL was installed in *one* working day. FOAMSIL has a coefficient of expansion of only .00000035. The stack has gained more cross-section area since only 2½ inches of FOAMSIL were required.

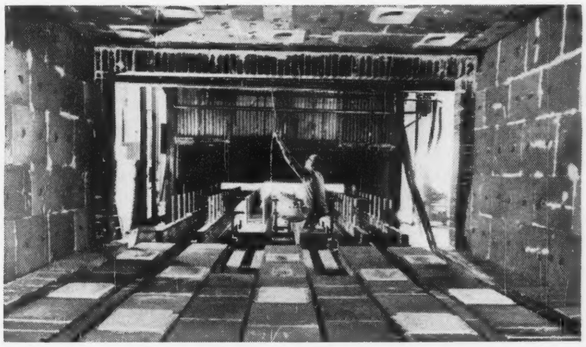
PITTSBURGH

solved major refractory and insulation problems for these users



PROBLEM: ACID EXPOSURE

FOAMSIL is completely resistant to all acids except hydroflouric and hot phosphoric. This protection against acids and acid vapors, fumes and liquids of all kinds led Union Carbide Chemicals Company to apply it in piping, stack, and vessel applications for sulphuric acid at their plant in South Charleston, W. Va. FOAMSIL cannot become saturated with vapors or liquids. Carbide uses FOAMSIL insulation as a tank lining where the sulphuric acid content is as high as 95 per cent, and the temperatures sometimes soar to 480°F. Two mortars that are compatible with the qualities of FOAMSIL are Pennsalt Synar silica cement No. 68 and FOAMSIL No. 1120.



PROBLEM: LOW HEAT CAPACITY

Pacific Scientific, Bell Gardens, Calif., used FOAMSIL to line a portable brazing furnace because of its lightweight, extra-support strength and resistance to heat. A saving of 80 per cent or $80,000 over normal heating equipment was achieved because the use of FOAMSIL meant only a fraction of the usual firing equipment was needed. FOAMSIL's low residual heat capacity and low heat storage capacity make it possible to heat materials to the necessary high temperature rapidly and remove heat quickly to allow the braze to set. Five inches of FOAMSIL does the work, leaving more working area in the 91 ft. x 21 ft. furnace which handles honeycomb aircraft and missile sections measuring 12 ft. x 20 ft. and 4 ft. high.

Use the coupon to get a testing sample:
Test FOAMSIL for your most troublesome refractory or insulation application . . . from tank lining to insulation of furnace, oven or stack. FOAMSIL is available in block sizes 17″ x 22″ in a variety of thicknesses. Send for a free sample and literature to: Pittsburgh Corning Corporation, Department CO-100, One Gateway Center, Pittsburgh 22, Pa. In Canada: 3333 Cavendish Blvd., Montreal, Que.

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6001

List Given of 28 Publications Containing Corrosion Literature

About 28 publications concerned primarily with corrosion are available, according to a recent survey made by Hugh P. Godard, Aluminum Laboratories, Ltd., Kingston, Ontario, Canada, who was immediate past president of NACE.

The list given below includes several publications which are no longer printed but are of interest for reference purposes. The list does not include the Russian publications listed on Page 40 of the August issue of CORROSION.

Australia

Australian Corrosion Engineering, P. O. Box 250, North Sydney, Australia, Vol. 1, 1957 (monthly).

Czechoslovakia

Korose a ochrana materialu (Corrosion and Protection of Materials),Vyzkummy ustav ochrany materialu, G. V. Akimova, V mestanskeho pivovaru 4, Prague VII, Czechoslovakia, Vol. 1, 1957.

England

Corrosion Prevention and Control, Holland House, 140 Cromwell, London, S.W. 7, England, Vol. 1, 1954 (monthly).

Corrosion Technology, Leonard Hill Limited, Stratford House, 9 Eden Street, London, N.W. 1, England, Volume 1, 1954 (monthly). Formerly published with Chemical and Process Engineering.

France

Corrosion et Anti-Corrosion, Les Presses Documentaires, 28 Rue St. Dominique, Paris 7, France, Vol. 1, 1953 (monthly).

Journees sur la Corrosion des Metaux, Institut Francais du Petrole, 2 Rue de Lubeck, Paris 16e, France, first issue 1947 (irregular). Supplement to *Revue de l'institut francaid due petrole* et Annales des Combustibles liquides.

Metaux et Corrosion, 32 Rue du Marechal Joffre, St. Germain en Laye, Seine et Oise, Vol. 1, 1925 (monthly). Discontinued with Vol. 7, No. 3 (1941) and replaced with *Metaux, Corrosion, Industries* at same address.

Germany

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Holland

Corrosie-Instituut, T.N.O. Circulaire, Corrosie-Instituut, Postbus 49, Delft, Netherlands, Number 3 issued December, 1952 (irregular).

Japan

Corrosion Engineering, Japan Society for Promotion of Science, Committee of Preventing Corrosion, Ueno-Koen-chi, Taito-ku, Tokyo, Japan. Current issue: Vol. 9, No. 7, July, 1960 (monthly).

United States

Corrosion Magazine, National Association of Corrosion Engineers, 1061 M & M Bldg., Houston 2, Texas, Vol. 1, 1945 (monthly).

Corrosion and Material Protection, Corrosion Publishing Company, 1131 Wolfendale St., Pittsburgh 12, Pa., Vol. 1, 1945 (bi-monthly). Discontinued with Vol. 3, No. 5, Sept-Oct, 1948.

Readers are requested to submit additions and corrections to this list to Dale Miller, Corrosion Magazine, 1061 M & M Bldg., Houston 2, Texas.

New Plants

F. W. Gartner Company, 3805 Lamar Ave., Houston 1, Texas, is expanding its plant facilities to include an automatic grit blasting room, lathes, grinders, exhaust system and a new drying system for moisture and oil free air that are important in the metallizing process. The new plant is processing ceramic coatings for rocket nozzles with zirconium.

●

Monsanto Chemical Company, 445 Park Ave., New York 22, N.Y., has acquired about 650 acres of industrial land in Gloucester County, N.Y., 20 miles southwest of Camden, N.J., on the Delaware River for development as a plant site. The new plant will be designed to increase the company's phthalic anhydride capacity by over 30 percent and its phthalate ester capacity by over 50 percent.

●

E.I. du Pont de Nemours and Company is expanding its sulfuric acid plant at Wurtland, Ky., and is building a new bulk acid terminal near New Cumberland, W. Va., to provide service for the eastern Ohio and Pittsburgh areas.

●

A proposal has been placed before the Japanese government by Asahki-Dow Limited, an associated company of the **Dow Chemical Co.,** Midland, Mich., for construction of a polyethylene plant at Kawasaki, Japan.

●

Carborundum Company, Niagara Falls, N.Y., is operating its new research facility for work on the synthesis and fabrication of uranium carbide-plutonium carbide, a promising fuel combination for nuclear power reactors.

●

B. F. Goodrich Chemical Co., Cleveland, Ohio, plans to build a factory in Colombia to manufacture vinyl plastic materials in cooperation with Colombian participants. The Goodrich plant will be adjacent to the factory of Planta Colombiana de Soda at Zipaquira, near Bogota. The Colombian plant will supply chlorine, one of the primary raw materials used in making plastics.

Concrete Lined Pipe To Be Used for California Aqueduct

Thirty-two miles of 40-foot concrete lined pipe sections will be laid as part of the Mokelumne Aqueduct in California. The aqueduct is one of a series designed to provide fresh water to the Oakland area.

The 32-mile conduit will require 4289 sections of the concrete lined pipe. Each section will weigh 22½ tons and will have an 87-inch inside diameter.

The Mokelumne Aqueduct is a series of fresh water ducts. This 32-mile section is the second unit of the third series of conduits reaching from the Pardee Reservoir, east of Oakland, to the edge of the city.

The first two Mokelumne Aqueducts are discussed in an article titled "Interconnection of Pipe Lines Having Various Coatings" by David Hendrickson, published on Pages 212-216, CORROSION Magazine, Vol. 8, No. 6 (1952) June.

The concrete lined conduit will be placed in a trench having a maximum depth of 27 feet. Pipe sections will be welded with final concrete seals applied by troweling. Completion of this unit project is expected to require two years.

The project is being handled on a joint basis involving four companies: Contracting and Material Co., Evanston, Ill., Kenney Construction Co., Skokie, Ill., Foster-Marsch Corp., Pittsburgh, Pa., and Graver Tank & Mfg. Co., East Chicago, Ind. Graver has the responsibility for providing the concrete coated steel pipe. The other companies will be in charge of the necessary trenching, laying-in and backfilling.

Galvanizing Conference To Be Held in Switzerland

The sixth international conference on hot dip galvanizing is to be held in Switzerland at the Kursaal, Interlaken on June 4-9, 1961, instead of in France as originally planned.

Over 20 papers are scheduled for presentation to cover such topics as works practice, properties and corrosion resistance of galvanized coatings, welding galvanized steel, metallurgy of galvanizing, after-treatments and heating of galvanizing baths.

Preprints of the papers will be issued in French, German, Italian and English. Oral presentations of the papers will be simultaneously translated into the same four languages at the technical sessions.

Plumbing Short Course

The Third Short Course on Plumbing Problems will be held October 27-29 at the University of Michigan School of Public Health, 109 South Observatory St., Ann Arbor, Mich. The course is sponsored by the University of Michigan College of Engineering and the Michigan Department of Health.

Included in the program will be a discussion on the use of plastics in plumbing and a showing of the International Nickel Company film "Corrosion in Action."

Control Board of coating and wrapping schedules in the Plant Office.

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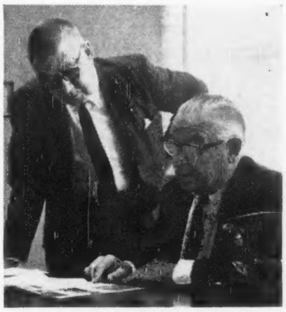

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V.P. Wilson discusses plans with V.P. Vondrasek.

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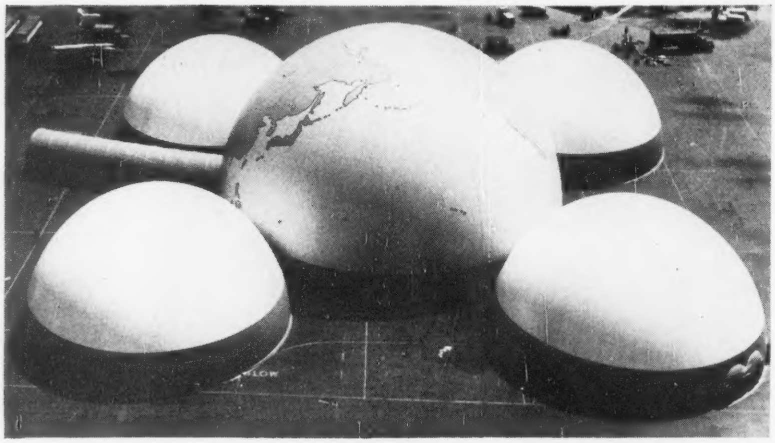

AIR SUPPORTED STRUCTURES large enough to house the largest missiles in horizontal or vertical position are made of a vinyl coated nylon fabric which is supported by low pressure air from high volume blowers. The large dome is as high as a nine-story building with a diameter of 150 feet.

Vinyl Coated Nylon Fabric Used For Temporary Air Structures

Temporary air structures for protection of equipment, material and outdoor displays have been designed from a vinyl coated nylon material which is supported by low pressure air from blowers.

Sizes of the structures range from 20 by 30 by 10 feet high to one that is as high as a nine-stoy building with a 150-foot diameter (the large dome in the accompanying photograph). This larger structure is being used as a missile maintenance shelter at Andrews Air Force Base near Washington, D. C. Heavy equipment can be moved in and out of the structures through pressure locks.

The structures are designed to withstand winds of hurricane force and temperatures as low as 40 degrees below zero.

The 150-foot diameter main dome shown is designed to accommodate today's largest missiles in horizontal or vertical positions. The combination fabric was developed by Sawyer Coated Fabrics Division of Farrington Texol Corp., Watertown, Mass.

A similar structure called the Pentadome was engineered, designed and fabricated by Birdair Structures, Inc., Buffalo, N. Y.

Smaller air structures are manufactued by Hoosier Tarpaulin and Canvas Goods Company, Inc., 1302 West Washington St., Indianapolis 6, Ind.

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Aluminum Panels Used To Make Portable Jet Landing Strips

Portable landing strips for high speed tactical jets have been fabricated of welded aluminum panels for use by the U. S. Marine Corps. The panels can be airlifted by helicopter or unloaded across a beach and assembled quickly to convert open country into smooth landing fields.

The airstrip surface made of high strength aluminum sheet resists the hot jet blasts and the impact from carrier-type landings. (See accompanying photographs.)

The panels were developed by modifying a basic landing mat section produced and used early in the 1950's. The corrugated aluminum sheet design of this earlier mat had demonstrated good corrosion resistance and high strength. The sections are mechanically joined lengthwise (12 by 2 feet panels). Each panel has 27 downward curving fingers along one side and slots along the other. The fingers of one panel are forced through the slots of an adjoining panel for couplings to withstand the jet aircraft landings.

For end-to-end couplings, butted ends are bolted together with aluminum bolts seated by an impact wrench.

Sandwich construction was used on the sections to obtain a strong surface free of depressions and holes in which dirt and debris could collect and then be sucked into the jets' intakes to damage the engines.

Aluminum for the panels was supplied by Aluminum Company of America.

Data Processing Devices Take Phone Calls on Cards

A low cost data processing device that answers the telephone and takes messages in the form of punched cards has been developed by International Business Machines Corp., 112 East Post Road, White Plains, N.Y.

The system transmits both fixed data from pre-punched cards and variable information keyed in manually on a keyboard. The receiving station accepts the data, simultaneously punching it into cards which are then ready for processing by an IBM computer or accounting machine. The system is designed for use in any size organization with one or more locations. Telephone lines are used for the inter-system communications, whether within a company office or across the country.

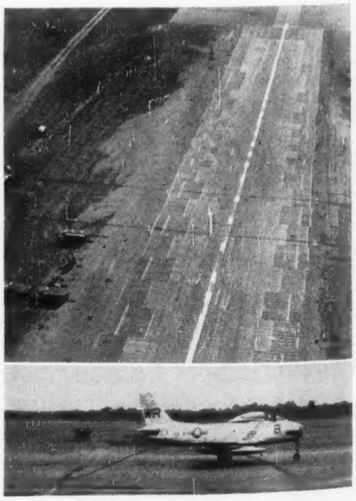
German Standards Available In English Translations

Four English translations of German standards on non-ferrous metals have been published. They are (1) 1709 Sheet 2, Copper-base coast alloys; cast brass and cast special brass, composition, December, 1953, (2) 1712 Sheet 4, Highest grade aluminum and alloys produced with it, December, 1953, (3) 1714 Sheet 2, Copper-base cast alloys; cast aluminum bronze and cast aluminum bronze with additionals, composition, December, 1953, and (4) 1719, Materials; lead, April, 1951.

The translations are available from Deutscher Normenausschuss, Berlin W 15, Uhlandstrasse 175.

Packaging Short Course

A short course on industrial packaging will be held March 20-31, 1961, on the Purdue University campus, Lafayette, Ind. Additional information can be obtained by writing Mark E. Ocker, Division of Adult Education, Memorial Center, Purdue University, Lafayette, Ind.



ALL-ALUMINUM landing strips have been designed for portable use to handle jet aircraft landings. Mechanically joined, the panels are of a sandwich type construction with a corrugated sheet core enclosed by an aluminum alloy sheets.

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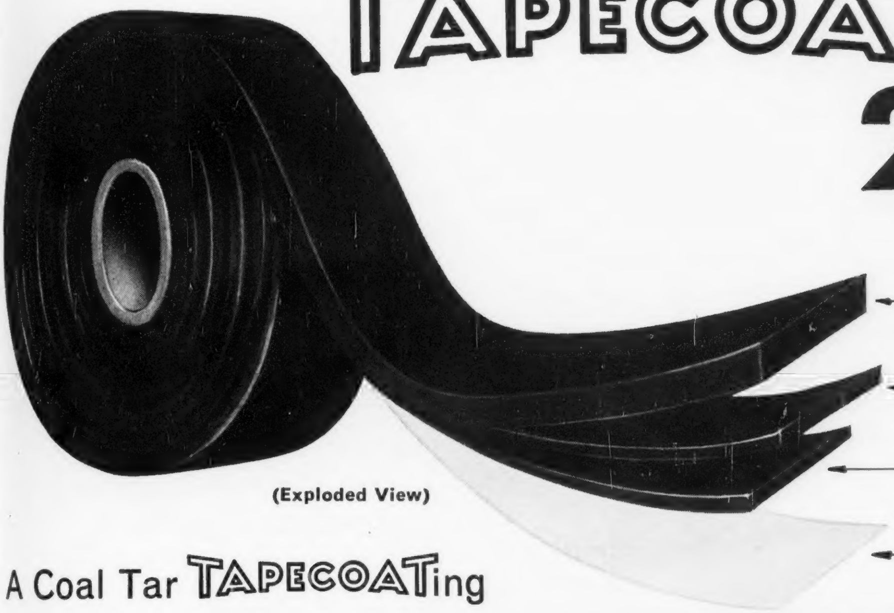

(Exploded View)

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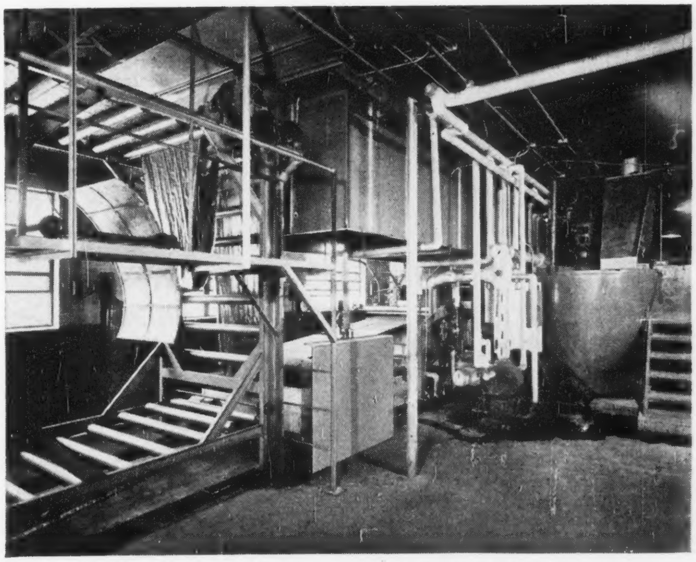

View of specially-designed machine developed after five years of research by Tapecoat engineers to convert raw materials automatically into TAPECOAT 20.

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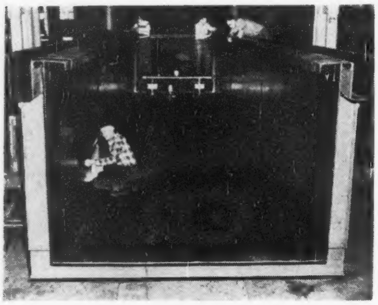


THREE-PLY RUBBER LINING is applied to this pickling tank for protection against corrosive acids. This large tank was designed as part of a 391-foot unit used for removing surface scale and rust from steel ribbons before they pass through cold rolling mills.

Thick Rubber Linings Applied to Protect Large Pickling Tanks

Large pickling tanks in which surface scale and rust are removed from steel ribbons before they pass through cold rolling mills are protected from the corrosive acids and its fumes by thick rubber linings. Workmen are shown in the accompanying photograph applying a three-ply course of acid resistant rubber.

The rubber is applied to each section of the tank which may contact the corrosive pickling acids. Each section then is vulcanized in a large autoclave to obtain a permanent bond of the lining to the steel and to insure maximum chemical resistance.

When the rubber lined sections are welded together to form the pickling tank, 12 inches of acid brick sheathing is placed on the inside walls and bottom for protection against physical damage and high temperature of the acid solution.

The tank shown in the photograph is part of a 391-foot pickling unit produced by Goodyear Tire & Rubber Company for U. S. Steel's Tennessee Coal & Iron Division at Fairfield, Ala.

Tanks, covers, duct work, walkways, fume scrubbers, blowers, exhaust stack and side guides for the pickling unit were made of steel and lined with the three-ply rubber for protection against corrosion from the acid and its fumes.

Pre-Assembled Units To Be Conference Topic

"Pre-assembled Components in Building" will be the theme of the three-day conference of the Building Research Institute to be held November 15-17 at the Shoreham Hotel, Washington, D. C.

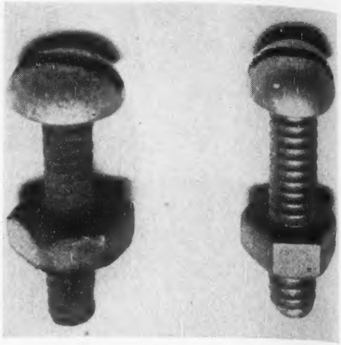
The conference also will include discussions on structural foams and a conference workshop on fasteners and anchorage devices for industrial curtain walls.

Preliminary program and registration material can be obtained by writing Milton C. Coon, Jr., Executive Director, Building Research Institute, 2101 Constitution Ave., N.W., Washington 25, D. C.

Industrial Finishes Show To Be Held in England

The First International Industrial Finishes Exhibition will be held at Earls Court, London, May 8-11, 1961. The exhibition will feature equipment, materials, plant and processes used in the industrial finishing field and exhibits on metal pre-treatments, paints and their application, electroplating, galvanizing, metal coloring, anodizing, plastic covering, mitreous enamelling, shot blasting and vacuum deposition.

Exhibition is being organized by the Exhibition Division of Scientific Surveys Ltd., 97 Old Brompton Road, S.W. 7, London, England.



ACID INHIBITOR added to the cleaning bath used on aluminum bolt on right prevented corrosion damage. Both bolts were immersed in the same strength muriatic acid for 24 hours.

Muriatic Acid Inhibitor Developed for Cleaning

A new corrosion inhibitor for muriatic acid has been developed for immersion cleaning. Metals susceptible to acid attack such as galvanized sheet or aluminum can be cleaned without corrosion damage, according to the manufacturer. The inhibitor is soluble in concentrated hydrochloric acids.

The accompanying photograph shows two aluminum bolts immersed in two acid baths of the same strength for 24 hours. The bolt on the right was immersed in the acid to which the inhibitor was added and shows no corrosive damage.

Called Unicon, the inhibitor was developed by Developments Unlimited Incorporated, 328 Broadway, Passaic, N. J.

Focus on Plastics in Process Equipment

The November issue's Technical Topics Section will be devoted to discussing the use of plastics for process equipment, Other interesting articles on plastics will be featured in that issue also.

Australian Corrosion Group To Hold First Conference

The first annual conference of the Australian Association for Corrosion Prevention will be held in Melbourne, Australia, October 31-November 3. Technical sessions will be devoted to practical and theoretical methods of corrosion control. Plant inspections and social events will be included as part of the conference program.

●

Northeast Region's 1960 Conference will be October 11-14 at the Prichard Hotel, Huntington, W. Va.

●

The 1960 North Central Region Conference will be held Oct. 19-20 at the Schroeder Hotel in Milwaukee, Wis.

●

NACE's Bibliographic Surveys of Corrosion extend from 1945 to 1955. Prices available upon request.

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AMCHEM Information Bulletin

Facts about pickling acid inhibitors

Nearly 40 years ago Amchem developed the first pickling acid inhibitor—RODINE—and with it revolutionized acid pickling. Only a few of the steel mills of the time believed that the addition of less than one percent RODINE to a sulfuric acid pickling bath could save substantial amounts of acid and metal, while increasing the life of the bath. Today there is no mill chemist who does not know about RODINE and its proven performance in eliminating waste of valuable metal and acid, and its ability to pay for itself through the savings thus gained.

In the past few years much attention has been focused on the use of wetting agents to accelerate pickling. But the fact remains that pickling cycles cannot be reduced by the use of wetting agents alone without severe overpickling problems. Wetting agents do help the acid run off surfaces removed from pickle baths, and, in so doing, reduce carry-over of acid into the rinse.

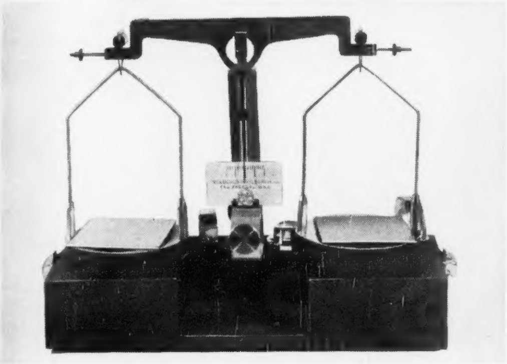
Wetting agents should not be confused with inhibitors to protect the metal and save acid wasted in pitting it. They should not be expected to miraculously speed the removal of scale, even at the expense of wasting the metal. However, the *proper* combination of *real inhibitor* plus correct wetting agent can have beneficial effects on pickling practices.

Only a true inhibitor such as RODINE can offer steel producers solid advantages in pickling. Baths can be operated longer and less acid is required to keep them at desired concentration. Costs of charging and cleaning the bath are reduced, less handling and storing of acid is required. A RODINE bath produces far fewer rejects—steel emerges with uniformly smooth, bright clean surfaces, free of pits, blisters and smut.

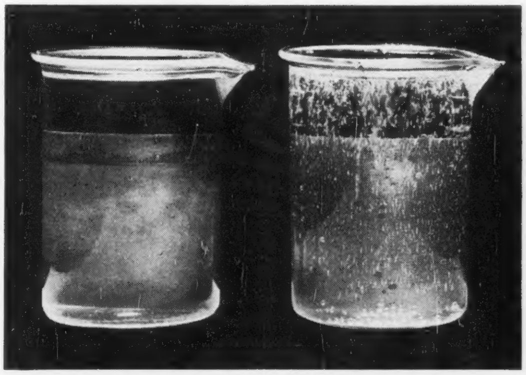
When an Amchem Technical Representative enters your pickle house, you can be assured of experienced assistance in improving your pickling. He will recommend the proper RODINE to 1) prevent needless consumption of acid after scale removal, 2) prevent smutting, pitting and overpickling, 3) produce a stable, free-rinsing foam blanket, 4) improve rinsability and reduce carry-over, and 5) produce a brighter, cleaner surface. Only the Amchem Representative can do this for you because he has at his command the most widely diversified and accepted line of real inhibitors and correct wetting agents available.

Since the early days of pickling acid inhibitor development, scientists in the Amchem Metal Protection Laboratories have constantly studied methods to make the RODINES stronger, more effective and more economical to use. The RODINES of today, as of 40 years ago, are in a class by themselves, have developed a reputation as *the international standard* in acid pickling inhibitors. The fruit of these years of laboratory research and experience in a highly specialized field, and the assistance of Amchem's trained field representatives—specialists in acid pickling techniques—are at your disposal for the asking.

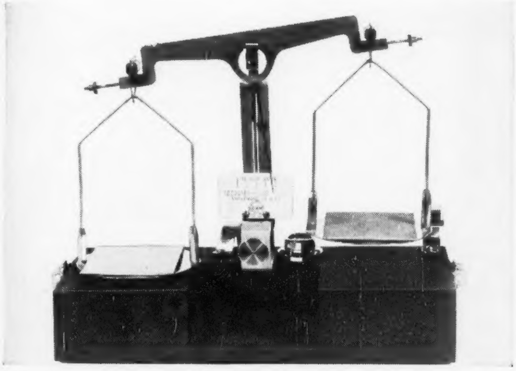
How Rodine Retards Acid's Attack on Metal



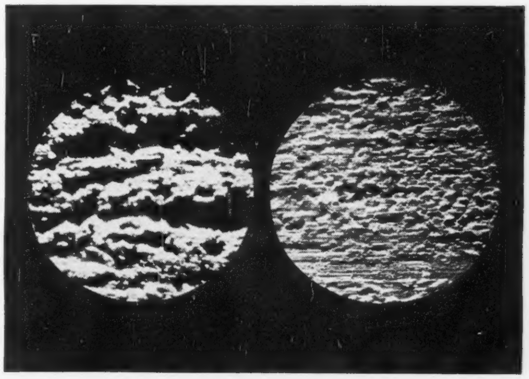
The photographs and microphotographs displayed on this page represent a graphic description of results demonstrating the effectiveness of RODINE in retarding the attack of acid on the metal. NO WEIGHT DIFFERENCE—two identical panels of low-carbon steel are shown being weighed here. They balanced the scale.



RODINE MINIMIZES ACID ATTACK—Each descaled panel was placed in a beaker containing 10% by volume of 66° Bé sulfuric acid of 160°F. The acid in the right-hand beaker was uninhibited. Acid in left-hand beaker was inhibited with RODINE 82, ¼% by volume of the concentrated acid. There was little or no hydrogen evolution in this beaker . . . RODINE retarded the attack of the acid on the base metal.



RODINE SAVES METAL—Both descaled panels were removed from the acid pickle solutions after 5 minutes. The one pickled in the uninhibited acid had lost 1.4% of its original weight. The one pickled in the RODINE-inhibited acid had lost only 0.001% of its original weight. This represents a saving of 26 lb. of steel for each ton pickled; and a simultaneous saving of nearly 50 lbs. of 66° Bé sulfuric acid when RODINE is used to inhibit the acid.



EFFECT OF UNINHIBITED ACID ON THE PANEL—This microphotograph of the low-carbon sheet steel pickled in the uninhibited acid shows deep pits and the crystalline character of the surface after 5 minutes in the solution.

EFFECT OF RODINE-INHIBITED ACID ON THE PANEL—This panel was pickled for 5 minutes in the RODINE-inhibited acid, then microphotographed. Only scale pockets and roll marks are visible; no pitting of the low-carbon sheet steel occurred.

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Equipment Services NEW PRODUCTS Materials Literature

Coatings, Application Equipment

Epoxy resins can be sprayed onto most surfaces for coatings of almost any desired thickness with a new hand-held plasma jet spray gun, according to the manufacturer, Plasmadyne Corp., 3839 S. Main St., Santa Ana, Cal. Called the Plasmatron jet spray gun, it gives good penetration of the resins for coating such complex items as electric motor stators and rotors, according to Plasmadyne engineers.

•

Elimination of a purge cycle, pile-up and clogging is claimed for a new spray designed to apply foam-in-place insulation such as rigid urethane foam and similar types of materials. Manufactured by the DeVilbiss Company, Toledo 1, Ohio, the spray gun mixes materials outside the gun, thus permitting mixing of fast setting components after they leave the nozzle. Spraying of other catalyst type materials is being tested. The foam spray unit includes a paint heater with attached air transformer, two 10-gallon catalyst type pressure feed tanks, a two-gallon cleaning tank, two-component catalyst spray gun and necessary hose and attachments.

Coatings, Organic

Corrosion resistant properties of virgin leafed metallic lead have been added to epoxy based systems through a new treatment of standard leafed metallic lead pigment developed by Metalead Products Corp., Box 5, Station A, Palo Alto, Cal. This is a stearic-free dry flake metallic pigment of the ductile metal. The resulting epoxy composition can be applied by trowel, brush or spray, according to Metalead Products.

•

Elimination of brittleness and the resultant stress cracking is claimed for a flexible, amine-cured epoxy protective coating system developed by the Carboline Company, 32 Hanley Industrial Court, St. Louis 17, Mo. Known as Carboline Epoxy 188, the new system is recommended for maintenance protection in severe acid, alkaline and salt exposures. It can be applied over power-tool cleaned and sandblasted surfaces and is compatible with tight, residual epoxy coatings. It is applied at thicknesses from 3 to 4 mils per coat.

•

Paints designed for decorative purposes with chemical and heat resistant properties are described in technical bulletins available from Subox, Inc., Fairmount Plant, Hackensack, N. J. Other bulletins describe paints designed to give a dry film thickness equal to two standard coats with only a single brush or spray application.

•

Epoxy protection of pipe fittings, supports and other pipe hardware by economical spray application before shipment to the field is accomplished by use of Scotchkote 101, a one-part powdered epoxy resin, according to the manufacturer, Minnesota Mining and Manufacturing Co., 900 Bush Ave., St. Paul 6, Minn. Recently made available as a mill coating for pipe, this epoxy can be applied to fittings with portable equipment. Sprayed on heated parts with a flocking gun, the resin flows evenly to give a uniform, smooth coating which cures in less than 60 seconds, according to Minnesota Mining.

•

Coatings designed for minimum interruption maintenance in the food, chemical and paper industries are described in Bulletin P-57, available from Wilbur & Williams Company, 650 Pleasant St., Norwood, Mass. Some of the coatings included are epoxy, synthetic rubber and liquid zinc coatings and synthetic coatings for sub-freezing maintenance painting such as is necessary in frozen food lockers.

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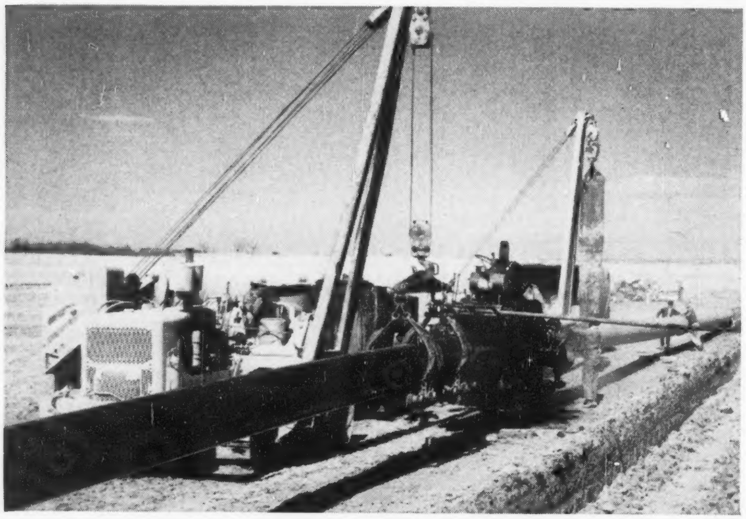
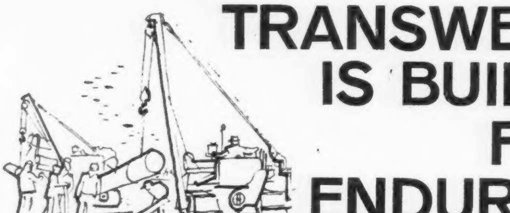
Protective coatings that cure at room temperatures for lining tanks that handle high purity water at temperatures in

(Continued on Page 50)





TRANSWESTERN IS BUILDING FOR ENDURANCE!

The Transwestern Pipeline Company line, with 1600 miles under construction from Fort Stockton, Texas and the Texas Panhandle to near Needles, California, will serve West Coast consumers with natural gas for many, many years to come. Its underground lines and structures are being installed with coal-tar enamel coating for high integrity electrical insulation and life-long corrosion protection. Reilly Hot Service Enamel with HS X-10 Primer and Reilly Intermediate Enamel with Q.D. Primer have been specified along with Coal Tar Enamels of other manufacturers and will serve as the engineering material of choice for corrosion mitigation.

Reilly COAL TAR PRODUCTS
ARMED Protective Coatings

REILLY TAR & CHEMICAL CORP.
1615 Merchants Bank Building
Indianoplis 4, Indiana

OSIVE LIQUID

after 2 years of chemical spills and weather...

HYPALON® Tank Truck Finish Shows No Damage...Stops Corrosion

For 2 years, the HYPALON coating on the exterior of this tank truck has withstood the daily ravages of 73% caustic soda spillage and year-round outdoor exposure . . . with no sign of damage.

When the truck was first put into service, caustic soda spillage at 130° F. deteriorated the original finish in a few weeks. To protect against inevitable rust and corrosion, the tank and undercarriage were recoated with HYPALON. Now spilling and splashing –plus 24-hour-a-day weather exposure –are no longer a problem. The carrier reports that HYPALON is the only coating they have found that can take this kind of punishment.

HYPALON, a Du Pont synthetic rubber, meets industry's need for a resilient material with outstanding resistance to acids, alkalies and strong oxidizing chemicals. Linings and coatings can withstand intermittent temperatures as high as 350° F. They are ozone-proof and resist abrasion, sun, weather, flame, oil and grease. For exterior coatings, HYPALON can be formulated in a range of attractive colors that resist discoloration.

Ask your coatings supplier about HYPALON coatings or write for your free copy of PROTECTIVE LININGS AND COATINGS. This comprehensive brochure is designed for engineers with a corrosion problem. E. I. du Pont de Nemours & Co. (Inc.), Elastomer Chemicals Department C-10, Wilmington 98, Delaware.

Finish on this caustic soda tank truck (upper area washed to show excellent condition of HYPALON coating) shows no damage after 2 years' service. Spillage like this destroyed standard finish within weeks.

DU PONT
REG. U. S. PAT. OFF.

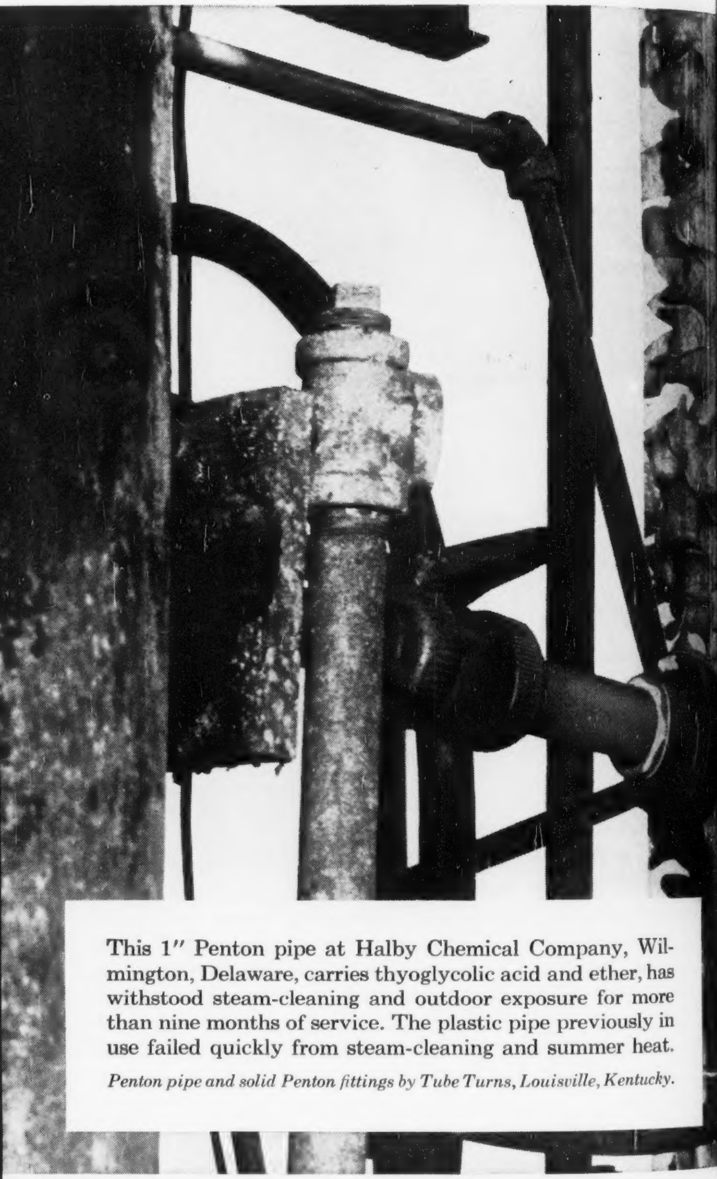
HYPALON®
SYNTHETIC RUBBER

Better Things for Better Living . . . *through Chemistry*

WHICH PENTON* PIPE

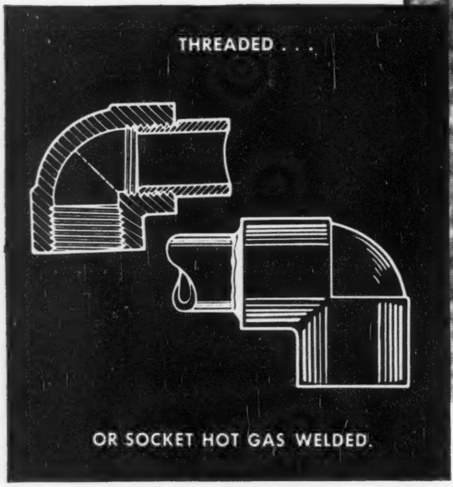
SOLID
PENTON PIPE:

A rigid, uniform pipe produced by extrusion, and available in sizes from ½″ to 2″ in either Schedule 40 or Schedule 80, in lengths up to 20 feet. Use in conjunction with injection molded, solid Penton fittings with socket or threaded connections (see diagram below). Provides both interior and exterior high temperature corrosion control. Today's most versatile, all-plastic pipe.



This 1″ Penton pipe at Halby Chemical Company, Wilmington, Delaware, carries thyoglycolic acid and ether, has withstood steam-cleaning and outdoor exposure for more than nine months of service. The plastic pipe previously in use failed quickly from steam-cleaning and summer heat.

Penton pipe and solid Penton fittings by Tube Turns, Louisville, Kentucky.



COMPLETE CORROSION CONTROL

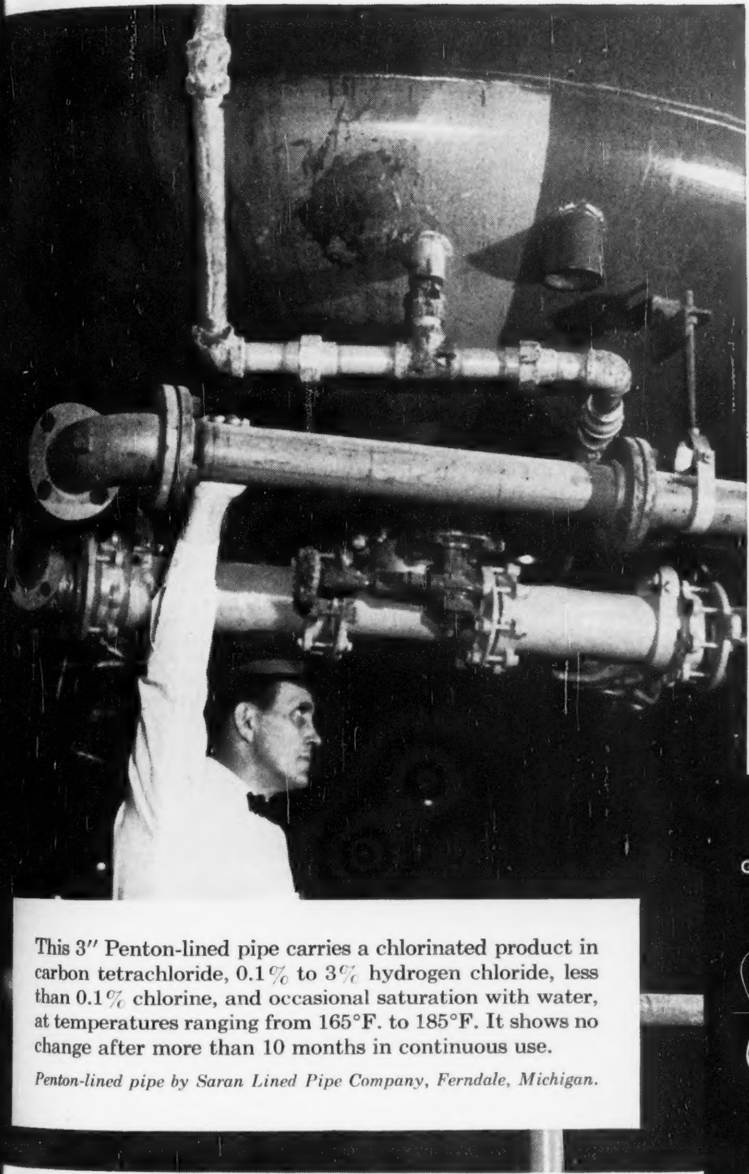
Inside and outside

High temperature resistance to a broad range of chemical reagents
Easily fabricated
Resistant to chemical atmospheres

Penton pipe and fittings, used in combination with other readily available Penton components for chemical processing, now make it possible to design a complete anti-corrosion system based on this versatile high temperature thermoplastic. Write for your copy of "The ABC's of Penton for Corrosion Resistance," which rates Penton's performance when ex-

**Hercules trademark for chlorinated polyether*

IS BEST FOR YOU?

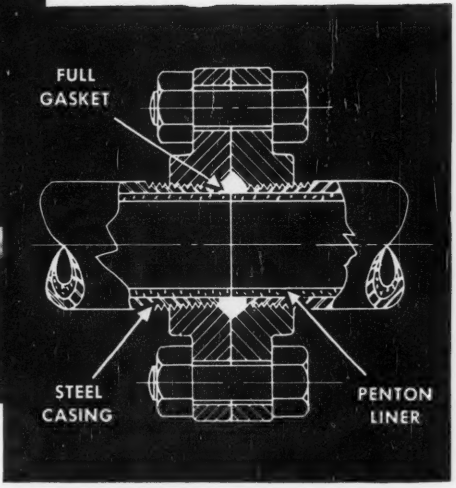


This 3″ Penton-lined pipe carries a chlorinated product in carbon tetrachloride, 0.1% to 3% hydrogen chloride, less than 0.1% chlorine, and occasional saturation with water, at temperatures ranging from 165°F. to 185°F. It shows no change after more than 10 months in continuous use.

Penton-lined pipe by Saran Lined Pipe Company, Ferndale, Michigan.

LINED
PENTON PIPE:

Steel pipe with a heavy Penton lining, available in sizes from 1″ to 6″ I.P.S. outside diameter, in lengths up to 10 feet. Joined by flanged gasket connection (see diagram below), it can be cut and fitted in the field without difficulty. Combines the outstanding high temperature, corrosion resistance of Penton with the structural strength of steel.



THE STRENGTH OF STEEL

and the properties of Penton

Excellent corrosion resistance at elevated temperatures
Economically installed
Safe, durable, and strong

posed to over 280 different chemicals and chemical reagents. Complete information on current sources for Penton products is listed in "The Penton Buyer's Guide," also available upon request.

Cellulose Products Department
HERCULES POWDER COMPANY
INCORPORATED
Wilmington 99, Delaware

CP60-8

NEW PRODUCTS

(Continued From Page 46)

the 200 F range are described in Technical Bulletin M-7 available from Wisconsin Protective Coating Corp., Green Bay, Wis. The bulletin gives six-year service records on Plasite 7155, which is designed for high temperature brine, caustic solutions and solvents.

Filters

A wet type dust collector without moving parts to provide maximum efficiency in cleaning air streams has been developed by the Metal Fabricators Division of the DeVilbiss Company, Toledo 1, Ohio. Called the Uni-Wash dust collector, the new unit removes contaminants from the air stream and deposits them as a wet sludge for manual or automatic removal from the units.

●

Stainless steel cores for liquid filter cartridges in installations having chemical or corrosive conditions are available for the Feutron filter cartridge made by American Felt Company, 2 Glenville Road, Glenville, Conn. The core is made of Type 304 stainless steel.

Instruments

Measurement of the moisture content in hydrogen streams can be made with a new electrolytic hygrometer cell, manufactured by the Scientific and Process Instruments Division of Beckman Instruments, Inc., 2500 Fullerton Road, Fullerton, Cal. The new cell is designed to remove and electrolyze most of the water from hydrogen gas streams with an insignificant amount of recombination. Beckman also is marketing a portable sulfur dioxide acrylyzer (automatic chemical reagent addition analyzer) designed to monitor and record low concentrations of sulfur dioxide in the atmosphere.

●

Stable amplifying of microvolts for operating strip chart recorders, indicators and other read-out devices can be accomplished by use of a new servo-amplifier Model SA-60C-4, manufactured by Schaevitz Engineering, P. O. Box 505, Camden, N. J. These units are designed to use the power of differential transformers or other sensing elements to actuate relays, small motors or for loads sensitive to phase inversion.

●

Continuous stream analyzers are described in a catalog available from Beckman Instruments, Inc., 2500 Fullerton Road, Fullerton, Cal. Included are industrial gas chromatographs, oxygen and infrared analyzers, electrolytic hygrometer, dissolved oxygen analyzer, flow colorimeter and a thermal conductivity gas analyzer.

Metals, Non-Ferrous

Longer electron tube life is one of the advantages claimed for cathode materials made by compacting metal powders of closely controlled composition. In this new process developed by Sylvania Electric Products, Inc., 730 Third Ave., New York 17, N. Y., high purity nickel or nickel with alloying powders is packed, sintered and rolled into strips from which cathodes are formed.

●

A high strength, corrosion resistant copper alloy that includes the desired qualities of silicon bronze is being produced by American Brass Company, Waterbury, Conn. Called Cunisil-837, it is an alloy of 97.50 percent copper, 1.90 percent nickel and 0.60 percent silicon. It has high tensile and yield strengths, high electrical conductivity, good corrosion resistance and good cold-forming characteristics before the hardening heat treatment, according to American Brass.

Plastics

Thermal and chemical stability of fluorocarbons have been designed into Penntube III, a new line of spaghetti tubing and monofilament extruded from a clear, modified trifluorochloroethylene polymer by Pennsylvania Fluorocarbon Co., Inc., 1115 N. 38th St., Philadelphia 4, Pa. Claimed to be impermeable and to have resistance to all inorganic corrosive liquids including oxidizing acids and to most organic solvents, the tubing is recommended for use with instruments, electrical sleeving, cable sheathings and flexible tubing for chemical process streams.

●

Homogenous extruded rigid vinyl sheet 50 inches wide and ranging in thickness from 0.060 to 0.125 inch has been developed by B. F. Goodrich Industrial Products Co., Akron, Ohio, for use in fabricating chemical plant equipment. This material is stocked in normal and high impact ⅛-inch sheets.

●

Exposed thread ends on pipe and conduits can be protected by plastic caps developed by Clover Industries, Inc., Tonawanda, N. Y. The caps are made of polyethylene and are color coded for identification. Applied by pushing onto pipe ends, the caps are designed to extend beyond the threads for protection during painting, dipping and handling operations.

●

Fifteen new formulations of the low and medium density polyethylenes have been added to the list of plastics produced by the Plastics Division of Koppers Company, Inc., Pittsburgh 19, Pa.

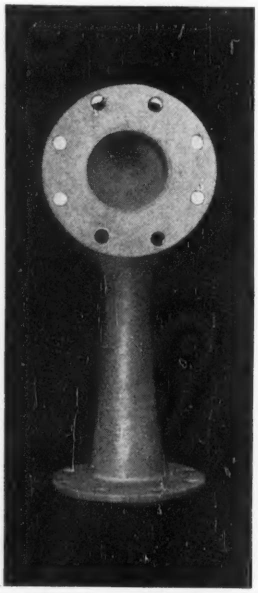
●

Corrosion resistance data on Penton, a thermoplastic polymer, are given in a chart available from Hercules Powder Company, Wilmington 99, Del. The chart gives new data on Penton pipe at 250 and 150 F. Case reports are given on corrosion resistance of solid Penton pipe and Penton lined metal pipe.

●

Chlorinated polyether tank linings have been added to the corrosion resistant materials used by U. S. Stoneware Company, Box 350, Akron 9, Ohio. Filling the temperature service gap between polyvinyl chloride and fluorocarbon, the new lining material is recommended for high temperatures for protection against organic and inorganic agents. It is claimed to be resistant to all inorganic acids except fuming nitric and fuming sulfuric acids. The tank lining material is extruded in roll form by U. S. Stoneware from a resin developed by Hercules Powder Co.

(Continued on Next Page)



Du Verre Completely Controls Corrosion in New S&K Gas Scrubbers

Now du Verre resin bonded fiberglass construction adds superior corrosion resistance to Schutte and Koerting's efficient Ejector-Venturi Scrubbers. Widely used throughout the process industries, SK 4010 units move large quantities of air and gas at low draft. They effectively remove dust and particulate matter, obnoxious vapors and corrosive gases.

Besides complete corrosion control, du Verre construction offers many other important advantages: Unlike lined equipment, venturi and jet can be accurately machined for more efficient operation. Erosive action of the high velocity venturi jet is minimized, even at temperatures approaching 300° F. High strength coupled with low weight eases handling and installation. The need for elaborate supporting steel is eliminated. Complete corrosion resistance on both exterior and interior surfaces eliminates need for painting and maintenance.

Investigate the many advantages of du Verre corrosion-resistant ducts, stacks, hoods, tanks, trays and specially-fabricated process equipment.

Write for Bulletin 101 Today!

du Verre inc.

du Verre, Incorporated • Box 37-L, Arcade, N. Y.

Testing

A quick and economical method of determining water hardness has been developed by the Micromet Division of Calgon Company, Hagan Center, Pittsburgh 30, Pa. Two reagents in dropper bottles and a glass vial are used to determine water hardness from one grain per gallon up. Readings can be made within one minute, according to Calgon.

●

A manual on methods and equipment for testing insulating materials is available from Associated Research, Inc., 3777 W. Belmont Ave., Chicago 18, Ill.

Water Treatment

Automatic water treatment control for cooling water systems has been developed by Associated Laboratories, Inc., 26845 Southfield, Lathrup Village, Mich. Called Hydrotrol, the system is designed to regulate water treatment control and bleed-off feed in proportion to rate of water evaporation or to the cooling load of the system.

●

Pre-treatment, waste disposal and other industrial water problems are discussed in a brochure available from Hall Laboratories, division of Hagan Chemicals & Controls, Inc., Hagan Center, Pittsburgh 30, Pa. Case histories are given showing process improvements resulting from more efficient uses of industrial water. A bibliography of 96 items including several on corrosion problems related to industrial water problems is given in the brochure.

Wire

High strength wire having 575,000-psi tensile strength has been developed by National-Standard Company, Niles, Mich. Made of high-carbon steel, the wire is available in sizes to 0.005-inch diameter. It is also available with brass finish in continuous lengths to two pounds and on spools to 10 pounds.

●

Yellow neoprene jackets on power cables give high visibility for safety to eliminate tripping over cables or running over them with heavy construction equipment. The new yellow cable, manufactured by Western Insulated Wire Co., 2425 E. 30th St., Los Angeles 58, Cal., has the same properties as black neoprene jacketed wiring that has been in use for outdoor applications for 25 years, according to the du Pont Company, producer of neoprene.

●

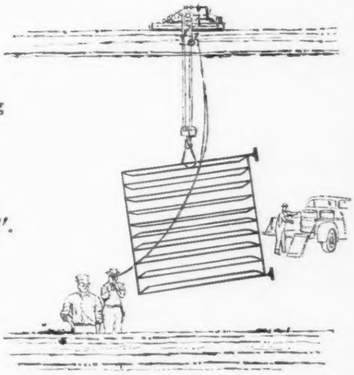
Heavy galvanized music wire with 10 to 15 times the corrosion resistance of standard tinned music wire is claimed by National-Standard Co., Niles, Mich. The zinc coating is three to seven per cent by weight.

●

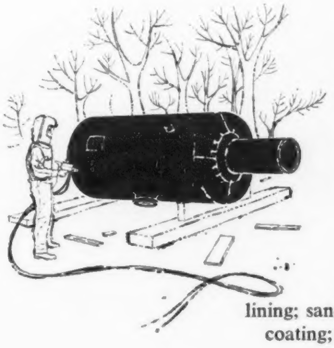
Coarse Sodium Wire converted from metallic sodium is described in a technical data sheet entitled "Laboratory Production and Use of Sodium Wire" available from U. S. Industrial Chemicals Co., Division of National Distillers and Chemical Corp., 99 Park Ave., New York 16, N. Y.

Nowery J. Smith Co. has the atmospheric corrosion prevention service you require

HOT-DIP GALVANIZING• Nowery J. Smith Co. is the most experienced galvanizer in the Southwest. Professional galvanizers assure that complex shapes, inside surfaces, and hard-to-reach areas—all—receive the same durable zinc coating. Applied according to ASTM or your own specifications.



PICKLING• For scientifically cleaning ferrous metals and stainless steel fabrications Nowery J. Smith Co. operates a complete pickling farm. Farm is equipped with seven pickling tanks in sizes up to 39′ 6″ by 3′ 4″ by 7′.



SPECIAL COATINGS• For structures and equipment requiring the protective advantages of zinc, aluminum, or other hot metal coatings, Nowery J. Smith Co. offers a complete metallizing service—applied in its plant or at your job-site. Additional special coatings and metal surface services include: Plioweld rubber lining; sand or shot blasting; painting; oiling; prime coating; epoxies and other task-tailored coatings.

When your next corrosion prevention problem arises, discuss it with a sales engineer from Nowery J. Smith Co., the Southwest's most complete corrosion prevention center. There's no obligation. Write, wire, or call:

LARGEST HOT-DIP GALVANIZERS IN THE SOUTHWEST

NOWERY J. SMITH CO.

8000 HEMPSTEAD HIGHWAY • P. O. BOX 7398 HOUSTON 8, TEXAS • UNderwood 9-1425

ONE OF THE SMITH INDUSTRIES —

MEN in the NEWS

Max E. Roha has been appointed manager of plastics research at the B. F. Goodrich Company Research Center, Brecksville, Ohio.

•

Albert Rozensky has joined the Corrosion Engineering Products Department staff of Pennsalt Chemicals Corporation, 3 Penn Center, Philadelphia 2, Pa., as technical service engineer.

•

Charles F. Simmers has been named chief engineer of the Engineering and Construction Division of Koppers Company, Inc., Pittsburgh 19, Pa.

•

NACE Member **John D. Stone** has resigned his position as Gulf Coast Division Corrosion Engineer with Sunray Mid-Continent Oil Company to go into business as a consulting corrosion engineer. He will make Corpus Christi, Texas, his headquarters and plans to open offices in Lafayette, La., and Houston later.

•

W. Andrew Wesley of Plainfield, N. J., an executive of the International Nickel Company, Inc., has been elected national president of the American Electroplaters' Society, Inc. 443-445 Broad St. Newark 2, N. J.

•

B. Q. Welder has been named manager of the newly created Oilfield Division of Hagan Chemical & Controls, Inc., Hagan Center, Pittsburgh 30, Pa.

•

NACE Member **Hugh L. Logan** of the National Bureau of Standards' Corrosion Section, Washington, D.C., has received a U. S. Department of Commerce Silver Medal for exceptional achievement in metallurgy, particularly in research on stress corrosion cracking of metals.

•

Robert L. Solnick has been appointed chief project engineer in sample handling systems of the Scientific and Process Instruments Division of Beckman Instruments, Inc., 2500 Fullerton Road, Fullerton, Cal.

•

H. A. Morley, NACE member at the Pearl Harbor Naval Shipyard, Honolulu, was named Federal Employee of the Year from a field of 29 nominees. A native of Oregon, he is a master painter and has degrees from Jackson College in Honolulu.

•

William H. Ailor, an NACE member who is senior corrosion engineer with Reynolds Metals Company, Richmond 18, Va., has been elected secretary of the ASTM's committee on corrosion of non-ferrious metals and alloys.

•

Richard A. Behrens has been appointed technical representative in the north central region for Union Carbide Plastics Company, 1300 Lakeside Ave., N.E., Cleveland, Ohio.

•

Ernest Loy Lane has been named regional metallurgist to handle technical service problems in the midwest area for Carpenter Steel Co., 4501 James Place, Melrose Park, Ill. **John W. Keegan** has been appointed metallurgist in hot and cold heading steels at the company's plant in Reading, Pa. Two other appointments are **Andrew R. Walsh** to assistant metallurgist of high temperature alloys and **Charles A. Divine, Jr.,** as assistant metallurgist in stainless steels.

•

NACE Member **Walter J. Braun** has joined the staff of the Industrial Applications Department at Nuclear Science and Engineering Corp., Pittsburgh 36, Pa.

•

Ted C. Combs, vice president of engineering at Zero Manufacturing Company has been appointed chairman of the Container Design Section, Packaging & Handling Division of the American Ordnance Association.

•

David Craig and **Forest W. Shaver** have been named research fellows at the B. F. Goodrich Company Research Center, Brecksville, Ohio. Research fellows, a new assignment category with the company, are free to explore fundamental research projects of their choice in line with company research and development policies.

•

Harry W. Fisher has been named manager of central liquid meter products engineering for Rockwell Manufacturing Co., 400 N. Lexington Ave., Pittsburgh 8, Pa.

•

Jack R. Grieve has joined the metallurgical department at Superior Tube Co., Norristown, Pa., to be in charge of non-destructive testing development for small metal tubing.

•

NACE Member **John P. Kleber** has been appointed manager of the newly organized Water Chemical Sales Division of Hagan Chemicals & Controls, Inc., Hagan Center, Pittsburgh 30, Pa.

•

Edwin Langhenry, an NACE member, has been appointed national sales manager for Erico Products, Inc., Cleveland, Ohio.

•

Robert D. Leslie has been appointed manager of Crucible Steel Company's sales branch in Charlotte, N.C. where he will reside at 2123 Forest Drive East.

•

Henry B. Linford, NACE member and professor of chemical engineering at Columbia University, New York City, has been awarded the Edward Goodrich Acheson Medal and Prize of the Electrochemical Society. The award, a gold medal and $1000 given every two years, will be presented during the society's October 9-13 meeting in Houston, Texas.

POSITIONS WANTED AND AVAILABLE

Active and Junior NACE members and companies seeking salaried employees may run without charge two consecutive advertisements annually under this heading, not over 35 words set in 8 point type. Advertisements to other specifications will be charged for at $12.50 a column inch.

Positions Available

Positions
in
CORROSION RESEARCH

Need experienced men for work on corrosion problems associated with petroleum and chemical industries. Positions require imaginative, aggressive, graduate level physical or electro chemists. Salary dependent on experience and training. Write:

Attn: Mr. E. J. Farrell
STANDARD OIL COMPANY (Ind.)
P. O. Box 431-A Whiting, Indiana

Corrosion Engineer—opportunity for salesman with large progressive manufacturer. Experienced man to handle advanced line of synthetic surface coatings. Man capable of building and eventually supervising complete group in area. Excellent salary, bonus and benefits. Reply in confidence. CORROSION, Box 60-30

Positions Available

Corrosion Engineer, to be sales consultant on patented corrosion-resistant tubular steel products on part time basis. Chemical or petroleum refinery experience helpful. New York City vicinity. Send resume to CORROSION, Box 60-28.

Opportunity Unlimited—seeking self-supporting partner in exploding sales agency. Be your own boss in protected territory selling plastic coatings; plastic fans, hoods, ducts, tanks, etc., to textile, pulp-paper, chemical plants in South Atlantic States. Plant engineering experience important. CORROSION, Box 60-29.

Positions Wanted

Sales-Promotion, 13 years successful industrial sales engineering experience in chemicals and corrosion resistant materials. Age 37, chemistry graduate, marketing post-graduate. Chicago preferred, Midwest travel. Familiar direct and distributor sales. Resume available. CORROSION Box 60-27

METALLURGICAL ENGINEER

The Chemstrand Corporation's nylon manufacturing plant at Pensacola, Florida is seeking a graduate engineer to assist the chief metallurgist in shop problems related to materials selection, welding, and heat treatment. Experience with chemical processing equipment desired.

Excellent working conditions and benefit programs. Attractive community life and living conditions in Gulf Coast location.

Send resume of academic training and experience to:

Manager,
Employment-
Recruitment

BOX P-3
THE CHEMSTRAND CORPORATION
DECATUR, ALABAMA

only the *best*
for the biggest

One of 180 grounding electrodes installed to depths of 60 ft. under Houston's newest skyscraper, slated to be the tallest structure west of the Mississippi.

Large or small, Cathodic Protection Service provides turnkey installations. Let one of our experienced engineers show you how Cathodic Protection Service can best solve your individual corrosion problems. Call, wire or write the CPS office nearest you.

CPS

cathodic protection service

P. O. Box 66387 Houston 6, Texas JA 6-1981

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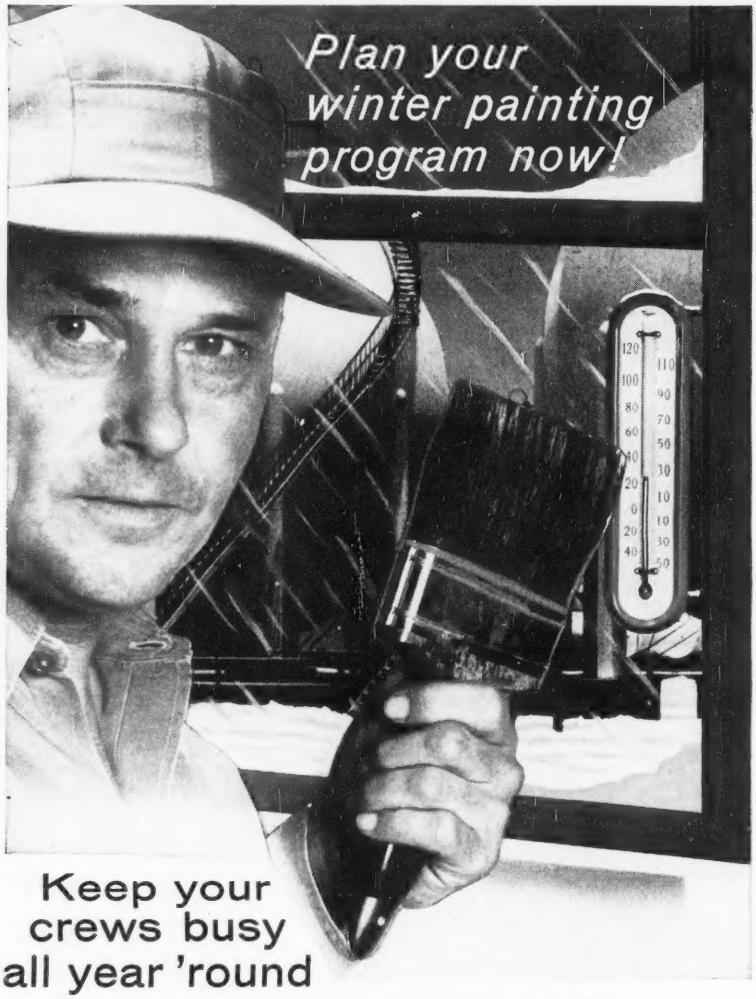
WEbster 9-2763

NEW ORLEANS
1627 Felicity
JAckson 2-7316

TULSA
4407 S. Peoria
RIverside 2-7393

CORPUS CHRISTI
1620 S. Brownlee
TUlip 3-7264

ODESSA
5425 Andrews Hwy.
EMerson 6-6731



Keep your
crews busy
all year 'round

with CARBO ZINC 11*

the all-weather maintenance coating

Most maintenance paints cannot be applied below 40° F. Not so with Carbo Zinc 11 ... *the only protective coating that can be applied outdoors in cold weather.* Paint *anytime*, 12 months of the year, indoors or out ... keeping a *smaller* crew busy full time. You still get protection far superior to standard maintenance paints.

- a zinc-filled inorganic protective coating
- water insoluble 20 minutes after applying
- fast drying, long-lasting galvanic protection for steel
- apply in humidity up to 95%, temperatures from –20° F. to 150° F.
- excellent resistance to water, coastal environment, brine, humidity, solvents

Use Carbo Zinc 11 without topcoat, or as primer with vinyl, Hypalon, epoxy, or inorganic topcoat. Resists undercutting and subfilm corrosion. Low material, application and maintenance costs.

Write for information, technical data, uses and samples. Also, see our catalog in CEC, pages 911-914.

6011 *Patent applied for

Sales engineers in principal cities.
Consult your telephone directory.

carboline
COMPANY

32-A Hanley Industrial Ct. St. Louis 17, Mo.

MAINTENANCE
COATINGS
WITH EXPERIENCE

Over 60 Percent of Corrosion Show Is Sold Out

Booths to Be on Same Hotel Floor As Other Meetings

Over 60 percent of the booths for the 1961 Corrosion Show have been contracted for, according to R. W. Huff, Jr., NACE Exhibits Manager. An alphabetical listing of the companies which have contracted for booth space is given below.

The 1961 Corrosion Show will be held in conjunction with the 17th Annual NACE Conference, March 13-17, at the Hotel Statler-Hilton, Buffalo, N. Y. Booths will be located on the same floor of the hotel as most of the technical meetings so that registrants can visit the exhibition during free times. No technical symposia meetings have been scheduled for the afternoon of March 14, the day the Corrosion Show opens, so that all registrants will have an opportunity to see all the booths.

Diversity of Exhibits

A wide diversity of corrosion control equipment, methods, processes and services will be included in the booths. Qualified personnel from the exhibiting companies will be available to answer questions.

Color Slides of 1961 Show

Color slides of specific products or booth areas of those companies wishing to participate will be photographed during the Corrosion Show by NACE for preparation of a color slide-talk to be available for NACE section meetings throughout the country.

The color slides and a prepared script giving brief descriptions of the products photographed at the show will be available for program material at section meetings and for use by other interested groups.

NACE section program chairmen should contact Gilbert Rolak to make booking arrangements for the 1961 Corrosion Show slide-talk.

Show Brochures Available

Companies wishing to make arrangements for exhibits at the 1961 Corrosion Show should contact R. W. Huff, Jr., NACE Central Office, 1061 M & M Bldg., Houston 2, Texas. A copy of the Corrosion Show Brochure will be sent, giving complete details on the booth sizes, facilities available, booth locations, etc.

Companies to Exhibit

Alloy Steel Products Co., Inc., Aluminum Company of America, Amercoat Corporation, A. M. Byers Company, Carboline Company, Carpenter Steel Company, Centriline Corporation, Clementina Limited, Crucible Steel Company of America, Delaware Barrel & Drum Co., Inc., DeVilbiss Company, Cryogenics Corporation, Dow Chemical Company, Fibercast Company;

Garlock, Inc., Glidden Company, Gray Company, Inc., Harco Corporation, Heil Process and Equipment Corporation, Hercules Powder Company, International Nickel Co., Inc., Johns-Manville Sales Corporation, Knapp Mills, Inc., Koppers Company, Inc., Lebanon Steel Foundry, Lincoln Engineering Company, M. C. Miller Company, Minnesota Mining and Manufacturing Company;

National Carbon Company, Pfaudler Permutit, Inc., Pittsburgh Corning Corporation, Reilly Tar & Chemical Corporation, Resistoflex Corporation, Royston Laboratories, Inc., Shell Oil Company, Shell Chemical Company, Standard Magnesium Corporation, U. S. Stoneware Company, Truscon Laboratories, Wheelabrator Corporation and T. W. Williamson, Inc.

Adams Appointed to EducationCommittee

Mark F. Adams of Washington State University, Pullman, Wash., has been appointed to the NACE Committee on Education. He is head of the Chemistry-Spectroscopy Laboratories at the university.

Chairman of this committee is Norman Hackerman, University of Texas, Austin, Texas. Other members are F. B. Burns, General Asphalt, Inc., Wynne Wood, Okla., M. G. Fontana, Ohio State University, Columbus, Ohio, E. C. Greco, United Gas Corporation, Shreveport, La., J. J. Harwood, Office of Naval Research, Washington, D. C., R. B. Hoxeng, U. S. Steel Corp., Monroeville, Pa., Harry J. Keeling, consulting engineer, Los Angeles, Cal., and Aaron Wachter, Shell Development Co., Emeryville, Cal.

•

News intended for publication in Corrosion should be in Houston no later than the 10th of the month preceding month of publication.

Western Region

Portland Section heard Dean Burgan of Electric Steel Foundry Company speak on "Castings for Corrosion Resistant Applications" at the September 15 meeting.

•

San Francisco Bay Area Section used the NACE color slide presentation of the 1960 Corrosion Show held last March in Dallas for its September 13 meeting. The slides gave a review of the show for those persons who did not attend the NACE Dallas conference.

'59 Speller Awardee J. C. Hudson Retires

J. C. Hudson, winner of the 1959 Speller Award presented during the 16th Annual NACE Conference last March in Dallas, has retired from his position as head of corrosion research at the British Iron and Steel Research Association, London, England.

He will continue to work with the British Association as consultant to the Corrosion Advice Bureau and the Chemistry Department. He has been in charge of corrosion research with the association since its formation in 1945.

He has written two books ("Corrosion of Iron and Steel" and "Protective Painting of Structural Steel") and over one hundred technical papers.

In addition to the Speller Award, he has received the 1960 Sir Robert Hadfield Bronze Medal awarded by the Iron and Steel Institute for his contributions to corrosion engineering and ferrous metallurgy.

•

The 1960 North Central Region Conference will be held Oct. 19-20 at the Schroeder Hotel in Milwaukee, Wis.

•

The 1960 South Central Region Conference will be held October 25-28 at the Mayo Hotel, Tulsa, Okla.

•

NACE's 18th Annual Conference and 1962 Corrosion Show will be held March 18-22, 1962, at the Municipal Auditorium in Kansas City, Mo.

•

News deadline for Corrosion is the 10th of each month.

DEATHS

Harold L. Stockdale, owner of Stockdale, Inc., Houston, Texas, died August 19 from a heart attack. A member of NACE since 1951, he had been associated with Koppers Company, Insul-Mastic Corporation and Industrial Waterproofing Company. He was a graduate of the University of Pittsburgh.

•

Joseph Frank Putnam, former president and general manager of Anti-Corrosion Manufacturing Company in Atlanta, Ga., died in Berkeley, Cal., after a long illness. An NACE member until his retirement because of ill health in 1958, he had been associated with Reynolds Metals Company and the Porter Company before joining Anti-Corrosion Manufacturing.

•

John M. Kamenar, an NACE member associated with Republic Oil Refining Co., Texas City, Texas, died July 22 of a heart attack.

Southeast Region

Cathodic Protection and Coatings to Be Emphases of Florida Short Course

Cathodic protection and coatings for corrosion control will be emphasized during the November 7-11 Florida General Conference Annual Corrosion Short Course to be held at Key Biscayne Hotel, Miami.

NACE Vice President E. C. Greco of United Gas Corp., Shreveport, La., will open the short course with an address on the activities of NACE. Registration will be Monday morning, November 7.

Discussions and technical papers scheduled for the short course are listed below with moderators for each session.

Monday, November 7

Moderator J. B. Prime, Jr., Florida Power & Light Co., Miami.

Corrosion and Management, by Solon Walker of East Tennessee Natural Gas Co., Knoxville, Tenn.

Army Missile Activities at the Missile Range, by Col. James D. Sams of Patrick Air Force Base, Fla.

Tuesday, November 8

Moderator C. Montague, Peoples Gas System, North Miami, Fla.

Fundamentals of Corrosion and Cathodic Protection, by A. W. Peabody of Ebasco Services, Inc., New York, N.Y.

Basics of Protective Coatings, by G. K. Vogelsang of Gates Engineering Co., Wilmington, Del.

Wednesday, November 9

Moderator for cathodic protection session: R. F. Hadley, Sun Pipe Line Co., Philadelphia, Pa.

Galvanic Corrosion, by T. P. May of International Nickel Co., Inc., Wrightsville Beach, N.C.

Pipe Type Cable, by Ed Merrill of Phelps Dodge Co., New York, N.Y.

Instruments and Testing Equipment Used in Corrosion Mitigation, by A. L. Ayres of New Jersey Bell Telephone Co., Newark, N.J.

Stress Corrosion of Steels for Aircraft and Missiles, by E. H. Phelps of U. S. Steel Corp., Monroeville, Pa.

Moderator for coating session: H. C. R. Folmer, Quelcor of Florida.

Preparation for Coating, Accent on Surface Preparation, by H. T. Rudolf of Atlantic Coatings Co., Jacksonville, Fla.

Application of Coating for Pipe, by Chris Georges, Pipe Line Service Corp., Atlanta, Ga.

Just Who Specifies Vinyl, by D. R. Meserve of Metal & Thermit Corp., New York, N.Y.

New Developments in Water Thinned Protective Coatings, by J. J. Lane of Koppers Company, Pittsburgh, Pa.

Mill Scale, by Kenneth Tator of Tator Associates, Coraopolis, Pa.

Thursday, November 10

Moderator for cathodic protection session: John Hancock, City of Jacksonville, Fla.

Condenser Tube Protection Through Use of Ferrous Sulfate, by T. W. Bostwick of the City of Jacksonville, Fla.

Condenser and Heat Exchanger Corrosion, by Wilson Lynes of Revere Copper and Brass Inc., Baltimore, Md.

Cathodic Protection of the 1600-Mile Tape Coated Pipe Line to Florida, by E. P. Doremus and R. B. Pass of Cathodic Protection Service, Houston, Texas.

Moderator for coating session: S. Miller of Miami Marine Research and Test Station.

Pre-Fabricated Polyethylene Coatings in Underground Corrosion Control, by H. D. Segoul of Kendall Company, Chicago, Ill.

High Build Protective Films, by F. C. Weber of Phelan-Faust Paint Mfg. Co., St. Louis, Mo.

Epoxy and Other Catalytically Cured Coatings, by A. G. Sternberg of Steelcote Mfg. Company, St. Louis, Mo.

Coating Comparisons, by J. W. Cushing of Carboline Company, St. Louis, Mo.

Friday, November 11

Moderator: R. Hadley of Sun Pipe Line Co., Philadelphia, Pa.

Sandblasting, by T. D. Skaggs of Clementina Ltd., Birmingham, Ala.

Panel discussion including all speakers on cathodic protection and protective coatings sessions.

Tour of Miami Seaquarium for inspection of recent corrosion control installation, conducted by E. J. Tilton, Jr.

Special Activities

Special activities for the short course include a fellowship hour, banquet and dance scheduled for Thursday evening, November 10, from 7 to 11 pm.

J. B. Prime, Jr., is director of the short course; C. H. Montague of Peoples Gas System is program chairman.

A ladies' program is being arranged by Mrs. E. S. Tilton, Jr., and Mrs. N. H. Bollinger, Jr.

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Birmingham Section has scheduled R. S. Woodruff of Alabama Power Company as guest speaker for the November 4 meeting. He will discuss his company's river development program.

J. W. Miller, Jr., was guest speaker at the September 9 meeting.

•

Southeast Region Conference for 1962 has been scheduled for October 11-12 in Birmingham, Ala.

•

The 1960 Southeast Region Conference will be held Oct. 6-8 at the Dinkler-Plaza Hotel, Atlanta, Ga.

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The American plastic industry tripled its production during the 1950's from 1.6 billion pounds in 1950 to 5.4 billion pounds in 1959.

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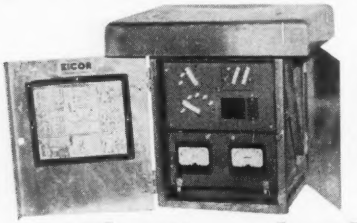

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South Central Region

Final Technical Program Changes Are Given for Oct. 25-27 Tulsa Conference

Twenty-four papers are scheduled for presentation during the October 25-27 South Central Region Conference to be held at the Mayo Hotel, Tulsa, Okla. The papers will be given at six technical symposia.

Registration fee will be $15 for NACE members and $17 for non-members. Registration fee for ladies accompanied by a full registered member will be $7.50. Registration fee will cover all activities given in the conference program which includes admittance to all technical sessions, fellowship hour and annual banquet.

A list of the technical papers to be given at each symposia is given below.

Oil and Gas Pipeline

Economics of Deep Ground Beds, by F. A. Therrell, Jr., Interstate Oil Pipe Line Co., Shreveport, La.

Selection of Bituminous Coatings for Pipelines, by F. B. Burns, General Asphalts, Inc., Wynne Wood, Okla.

Steps to Reduce Cost of Pipeline Corrosion Control, by N. K. Senatoroff and T. J. Degnan, Pacific Lighting and Gas Supply Co., Los Angeles, Cal.

Use of Analog Network Calculator in Design of Cathodic Protection Systems for Distribution Piping, by C. L. Woody, United Gas Corp., Houston, Texas.

Oil and Gas Production

Acid Volume and Inhibitor Quantity—Their Effect on Corrosion of Steel in Hydrochloric Acid, by William E. Billings, Halliburton Oil and Cementing Co., Duncan, Okla.

Pitting Corrosion in Waterflood Brines, by P. J. Raifsnider and A. Wachter, Shell Development Co., Emeryville, Cal.

Summary of Waterflood Corrosion, by L. C. Case, Tulsa, Okla.

Cathodic Polarization of Steel in Various Environments, by A. R. Erben, Sun Oil Co., Dallas, Texas.

Chemical Processing and Refining

Acid Corrosion Inhibition With Secondary Acetylenic Alcohols, by J. C. Frankhouser, Air Reduction Chemical Co., Bound Brook, N. J.

Zinc and Lead-Silver Anodes Solve Several Refinery Corrosion Problems, by G. E. Moller and J. T. Patrick, Union Oil Co., Rodeo, Cal., and J. W. Caldwell, Bunker Hill Co., San Francisco, Cal.

Technology of Inorganic Zinc Coatings, by J. B. Cox, Humble Oil and Refining Co., Houston, Texas.

Anodic Protection Against Sulfuric Acid Corrosion, by M. Hutchinson, N. L. Conger and C. E. Locke, Continental Oil Co., Ponca City, Okla.

Corrosion Resistance of Refractory Metals at Elevated Temperatures, by John R. Schley, Haynes Stellite Co., Kokomo, Ind.

Protective Coatings and Plastics

Glass Reinforced Plastic Pipe and Tubing in Chemical Service, by D. D. Kays, Frontier Chemical Co., Wichita, Kan.

Formulation and Application of a Bitumen Epoxy Coating for Pipelines, by F. James, Allied Division of H. K. Porter Co., Tulsa, Okla.

Practical Look at Pipeline Coatings, by J. C. Bell, Service Pipe Line Co., Tulsa, Okla.

Economy in Airless Spraying Vinyls, by D. L. Du Puy, Union Carbide Chemicals Co., Texas City, Texas.

Water Handling

Inhibition of Mineral Scales, by L. W. Jones, Pan American Petroleum Corp., Tulsa, Okla.

Comparative Laboratory Evaluation of Rapid Corrosion—Inhibitor Screening Test, by J. Wade Watkins and J. Costango, Bureau of Mines, Bartlesville, Okla.

Corrosion in Water Flood and Salt Water Disposal Systems, by H. D. Holloway and T. W. McSpadden, Pan American Petroleum Corp., Tulsa, Okla.

Microbiological Corrosion in Water Floods, by J. M. Sharpley, Buckman Laboratories, Inc., Memphis, Tenn.

Corrosion Survey and Testing

Methods of Testing and Evaluating Pipeline Coating in the Laboratory, by

CSI

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116 Oil Wells (West Texas). 2 casing leaks had resulted from external corrosion in this field. CSI ran current requirement tests, then installed rectifiers and graphite anodes on each well. Cost was only $300 to $350 per well.

Pipe Line (Southern Oklahoma). This line is operated by a major company. A cathodic protection system using 15 rectifiers was installed. CSI furnished all materials, labor, 15-foot augers, ditchers and other necessary equipment.

30 Oil Wells (Western Kansas). CSI determined current needed to stop corrosion; then installed 6-ampere-output rectifiers on a turnkey basis. Cost: $300-$350 per well.

Housing Unit Piping (Ohio). The builder of this housing unit wanted to prevent leaks and lengthen the life of the underground piping system. CSI recommended and installed a protective system using magnesium anodes. Anodes were used to lessen stray-current danger to nearby structures.

29 Oil Wells (West Texas). One casing leak had already occurred in this field. CSI installed protective systems using special new rectifiers that deliver almost constant current output despite heavy rains or dry periods.

Pipe Line (West Texas). Experience indicated that leaks would become an increasing problem. Protection was required. CSI installed 600 magnesium anodes in only 10 days.

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Ray Tuggle, Texas Pipe Line Co., Houston, Texas.

A New On-Stream Corrosion Inspection Technique, by Malcolm A. Meyn, Pittsburg Testing Laboratory, New Orleans, La.

Electrical Resistance Corrosion Probes—Problems and Pitfalls in Their Use, by David B. Boies, Nalco Chemical Co., Chicago, Ill.

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Tulsa Section held a panel discussion on the use of a dissolved oxygen meter at the September 26 meeting. Panel members were Lloyd Jones of Pan American Petroleum Research, L. C. Reynolds of Earlougher Engineering, Inc., R. L. Shaw of Humble Oil & Refining Co., Ed D. Parson of Phillips Petroleum Research, L. C. Case and J. Wade Watkins of the Bureau of Mines.

•

Shreveport Section heard Harold Dial of the East Texas Salt Water Disposal Company, Kilgore, Texas, speak on corrosion control in salt water disposal systems at the September 6 meeting.

•

New Orleans Section heard L. C. Edgar of Tube-Kote, Inc., speak on holiday testing of plastic coated tubing at the September 26 meeting.

•

Rocky Mountain Section had Kim Ellis of Hill-Hubbell speak on coating problems encountered with 13-foot diameter steel pipe at the September 16 meeting.

•

Alamo Section scheduled a social including a dinner for its September 20 meeting.

Max Schlather of United Gas Pipe Line Company discussed the article "Effect of pH on Corrosion at Elevated Pressures" at the August 16 meeting.

•

Houston Section will have Harold D. Singleton, project engineer at the Freeport Saline Conversion Demonstration Plant, speak on the salt water conversion plant at the October 11 meeting.

Donald W. Hood spoke on disposal of radioactive waste material at the September 13 meeting.

•

North Texas Section heard M. E. Carlisle of the Aluminum Company of America speak on aluminum for corrosion control applications at the September 12 meeting.

•

Central Oklahoma Section has scheduled a talk by R. D. McDonald of Oklahoma Natural Gas Company for the October 10 meeting. His topic will be "Design of Cathodic Protection System on Partially Coated 16-Inch Pipe Line."

Speaker for the November 14 meeting will be W. C. Koger of Cities Service Oil Company. His topic will be down hole corrosion.

D. H. Burton of Standard Magnesium Corporation spoke on the theory, design and use of magnesium anodes at the September 12 meeting.

•

The 1960 South Central Region Conference will be held October 25-28 at the Mayo Hotel, Tulsa, Okla.

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Over 20 million dollars was paid in 1959 to 39,000 employees of one company through the company's savings plan.

•

Western Region's 1960 Conference will be Oct. 6-7 at the Sheraton Palace Hotel in San Francisco, Cal.

•

Farmers in the United States produced 1.4 billion bushels of wheat and 3.8 billion bushels of corn in 1958.

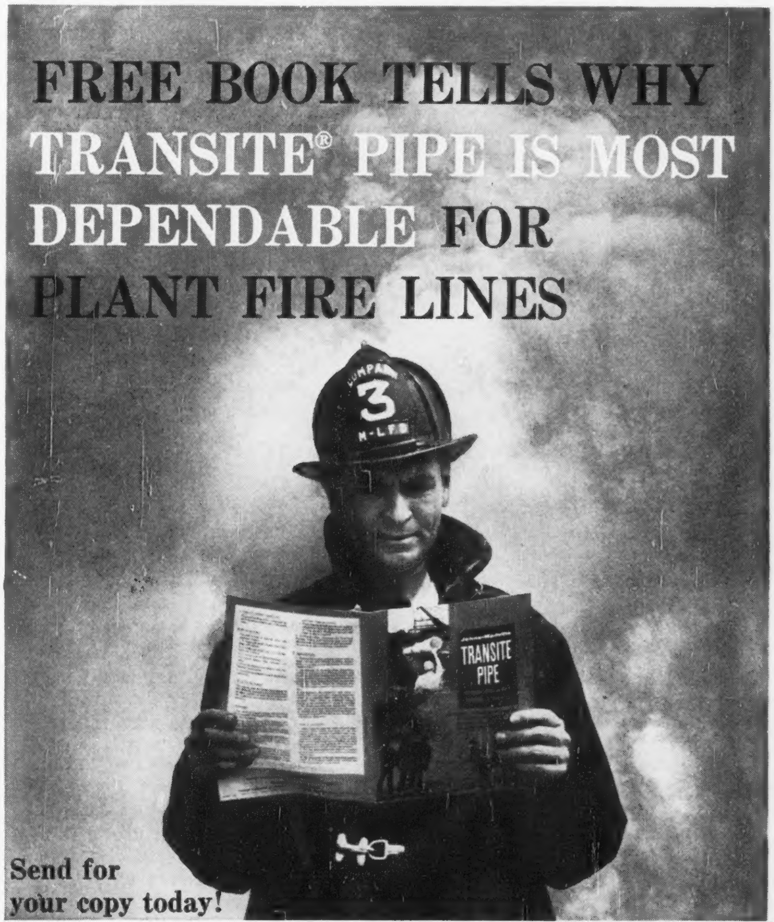
Attention Librarians

and others who bind CORROSION by Volumes!

The index to CORROSION's 1960 (Volume 16) issues will include alphabetical subject and author references to the articles published in the Technical Topics Section. The growing number and importance of these articles makes necessary to include them in the indexing.

•

Those who bind CORROSION by volumes and who customarily extract Technical Section pages are reminded that it will be desirable to extract also the Technical Topics Section and add it to the Technical Section of each issue. Although the Technical Topics Section does not have cumulative numbering of pages, it will be relatively easy to locate articles if this procedure is followed.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Foreign Corrosion Reports

Corrosion Prevention and Research in Israel

A report on corrosion activities in Israel during 1959 with a review of previous years has been received by the Inter-Society Corrosion Committee's Subcommittee on Relations with Foreign Organizations.

This report as printed below was submitted by NACE member D. Spector, Citrus House, 22 Harakevet St., Tel-Aviv, Israel.

Because this is the first report from Israel, a brief outline of activities is given in addition to the corrosion activities during 1959.

Israel obtained its independence in 1948, which marked a new phase in the country's growth and development. The vast activity in the rehabilitation of incoming refugees, doubling the population from 1.2 million in 1948 to 2.5 million in 1959, was paralleled by extensive waterwork, building activities, industrial development and considerable expansion in the merchant marine.

Attention has been focused on corrosion prevention although the pace of construction was too rapid to enable desirable corrosion prevention methods to be implemented. Some of these problems and achievements were outlined in a paper titled "Application of Cathodic Protection in Israel" presented at the 1956 Annual NACE Conference.

Corrosion activities are dealt with by various institutions and organizations, some of which are as follows: Corrosion Group of the Engineers' and Architects' Organization; Technion, Israel Institute of Technology; Israel Metals Institute; Israel Standards Institute; Water Planning for Israel Limited; Water Department, Jewish Agency Limited; and D. Spector Corrosion Engineers.

The Corrosion Group has taken the pattern of NACE and similar groups with the objective of giving engineers from every field an opportunity to discuss corrosion problems of mutual interest. Several lectures and symposia were held. The group plans to form technical practice committees in the near future.

In the educational field, the Technion, Israel Institute of Technology, has a leading role. The electrical engineering faculty has received several theses on cathodic protection. The Technion holds annual post graduate courses for engineers in industry. Corrosion and cathodic protection courses have been held for three successive years.

The Building Research Station of the Technion, headed by Professor R. Shalon, has done extensive work on corrosion problems of concrete and reinforcement.

The Israel Metals Institute is in its early stages of organization and plans to correlate and guide the metallurgical and fabrication industries in all matters pertaining to efficient use of metals.

The Israel Standards Institute pays considerable attention to corrosion problems in its standards legislation. Also the Institute's laboratories are conducting many tests at the request of industry relating to corrosion resistance of materials.

The Water Planning for Israel Ltd., responsible for the planning of the National Water Works, has engaged in problems such as aeration of water to reduce internal pipe corrosion, in investigating corrosion problems and cathodic protection in prestressed concrete pipes.

The Water Department of the Jewish Agency has explored a number of corrosion problems inherent in irrigation networks of agricultural settlements.

D. Spector Corrosion Engineers have been promoting cathodic protection in Israel and have also extended their operations overseas, primarily in ship and tanker corrosion, in which field they hold world patents.

NBS Adds New Division

The National Bureau of Standards has added a new division entitled Instrumentation at the Washington laboratories. The new division will investigate the fundamental properties and limitations of instruments, of their components and materials and of measuring, recording and signal processing methods. G. Franklin Montgomery is chief of the new division.

•

The 1960 South Central Region Conference will be held October 25-28 at the Mayo Hotel, Tulsa, Okla.

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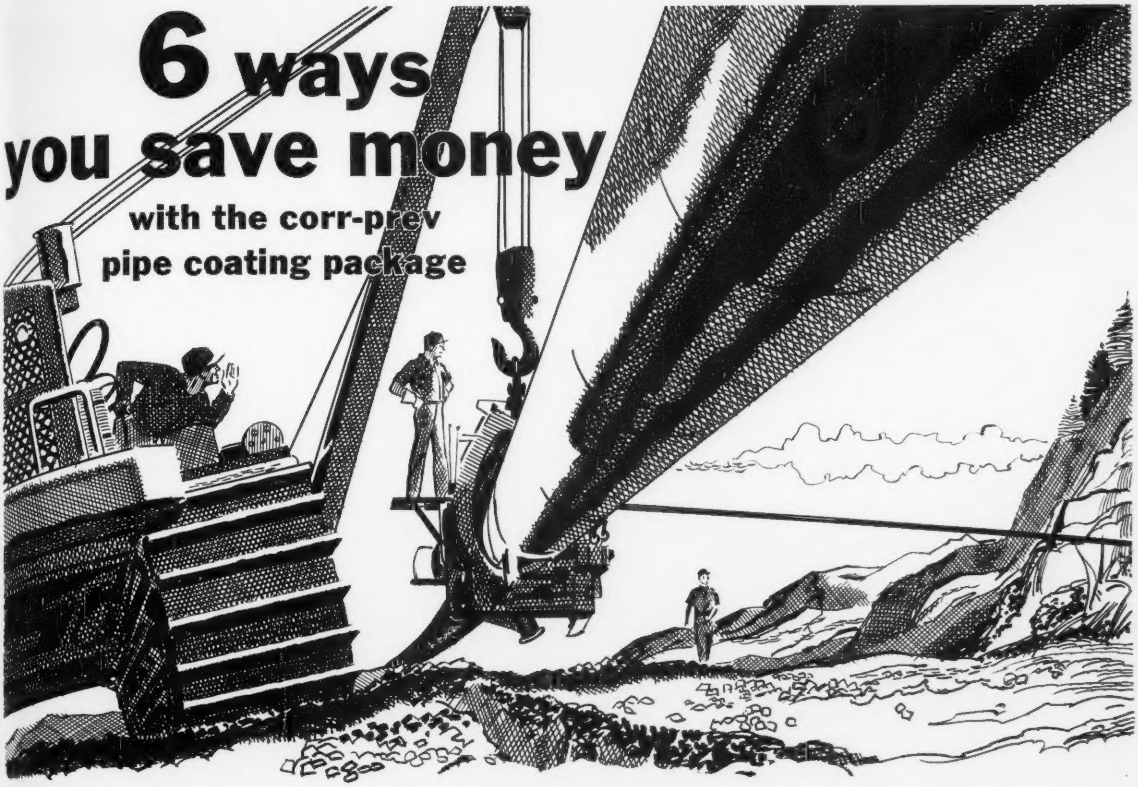

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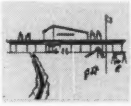

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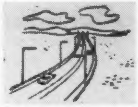

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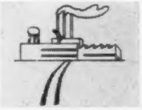

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North Central Region

Southwestern Ohio Section Plans 1960-61 Programs

Meeting dates and programs scheduled for 1960-61 have been printed on wallet size cards and mailed to all section members by the Southwestern Ohio Section to stimulate interest in the meetings.

The October 18 meeting to held in Cincinnati will include guest speaker John R. Schley of Haynes Stellite Division of Union Carbide Corp. He will speak on high temperature corrosion problems in the chemical industry.

Other meeting dates and programs for the year are given below.

November 29: Underground and Industrial Coatings, by W. E. Kemp of the Koppers Company, Inc., to be held at Middletown.

January 31, 1961: Panel discussion on cathodic protection, to be held at Dayton.

February 28: Fluidized Bed Method for Apply Plastics for Low and High Order Corrosion, by Fritz J. Nagel of the Polymer Corporation, to be held in Cincinnati.

March 28: Inhibitors and Chemical Treatments for Corrosion Protection, by William P. Innes of McDermid, Inc., to be held in Cincinnati.

April 25: Steels that Fight Corrosion, by John J. Halbig, Sr., of Armco Steel Corp. to be held in Connersville, Ind.

May 23: J. S. Long of the University of Louisville will be guest speaker. Meeting to be held in Cincinnati.

Officers recently elected for 1960-61 are Chairman Sylvan Falck, Vice Chairman Eugene E. Haney, Treasurer Arthur D. Caster and Secretary S. Clifford Jones.

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Cleveland Section held a plant tour of the Sohio Number One Refinery for its September 21 meeting.

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Detroit Section heard H. W. Schmidt of Dow Chemical Co., Midland, Mich., speak on some experiences with corrosion at the September 22 meeting.

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Chicago Section held a Ladies' Night program for its September 20 meeting.

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Kansas City Section has scheduled D. R. Werner of American Telephone and Telegraph Company to speak on experience with the deep anode bed at Danville, Ill., for the October 10 meeting. This will be the second meeting on deep ground beds.

International Nickel Company's film "Corrosion in Action" was shown for the September 12 meeting.

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Twin City Section held a discussion on corrosion problems associated with the paper industry at its September 20 meeting.

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Northeast Region's 1960 Conference will be October 11-14 at the Prichard Hotel, Huntington, W. Va.

NATIONAL and REGIONAL MEETINGS and SHORT COURSES

1960

Oct. 6-7—10th Annual Western Region Conference, Sheraton-Palace Hotel, San Francisco, Cal.

Oct. 6-8—Southeast Region Conference, Dinkler-Plaza Hotel, Atlanta, Ga.

Oct. 11-14—Northeast Region Conference. Prichard Hotel, Huntington, W. Va.

Oct. 19-20—North Central Region Conference. Pfister Hotel, Milwaukee.

Oct. 25-27—South Central Region Conference. Mayo Hotel, Tulsa.

November 14-16—Eastern Division, Canadian Region Conference, Hotel Royal, Montreal.

November 17-18—NACE Board of Directors Meeting, Sherman Hotel, Chicago, Ill.

1961

March 12—NACE Board of Director's Meeting, Hotel Statler, Buffalo, N. Y.

March 13-17—17th Annual Conference and 1961 Corrosion Show, Buffalo, N. Y., Hotel Statler.

March 17—NACE Board of Director's Meeting, Hotel Statler, Buffalo, N. Y.

Oct. 4-6—Western Region Conference, Hotel Multnomah, Portland, Oregon.

Oct. 9-11—North Central Region Conference, St. Louis, Chase Park Plaza Hotel.

Oct. 24-27—South Central Region Conference and Exhibition, Shamrock-Hilton Hotel, Houston.

Oct. 30-Nov. 2—Northeast Region Conference, New York City, Hotel Statler.

Southeast Region Conference, Miami, Fla., in conjunction with Miami Section's short course.

1962

March 19-23—18th Annual Conference and 1962 Corrosion Show. Kansas City, Municipal Auditorium.

October 1-4—Northeast Region Conference, Hotel Sheraton Ten Eyck, Albany, N. Y.

October 9-11—North Central Region Conference.

October 11-12—Southeast Region Conference, Birmingham, Ala.

October 16-19—South Central Region Conference and Exhibition, Granada Hotel, San Antonio.

SHORT COURSES

1960

October 12-13—San Joaquin Valley Section Biannual Corrosion Tour Registration at Bakersfield Inn, Bakersfield, Calif.

November 7-11—Annual Florida General Conference Corrosion Short Course, Key Biscayne Hotel, Miami. Sponsored by Miami and Jacksonville Sections.

•

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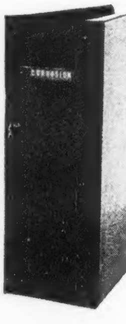

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Canadian Region

Final Changes Given For Eastern Division Nov. 14-16 Program

Final changes and additions to the program for the November 14-16 conference of the Canadian Region's Eastern Division have been made. The changes given below refer to the program scheduled published on Page 68 of the September issue of CORROSION.

Abstracts of some of the technical papers to be presented are given below.

Guest speaker for the luncheon on November 14 will be H. A. Webster of Corrosion Service Ltd. Speaker for the November 15 banquet will be L. R. Thiesmeyer, who is president of the Pulp and Paper Research Institute of Canada.

The title of the paper by W. A Mueller to be presented November 14 has been changed to "A Derivation of the Anodic Dissolution Curve of Alloys From Those of the Metallic Components."

"Engineering Design for Corrosion in Aluminum Water Pipe" is the new title for the paper to be presented by H. P. Godard of Aluminium Laboratories, Ltd.

The new title for the paper by R. D. Taylor to be given November 15 is "Recent Trends in Anode Mounting on Ships and Piers."

The paper by C. Birkett for Wednesday morning, November 16, has been changed to "The Economic Choice—A Method for Deciding."

Two papers have been added to the Wednesday morning session: "Role of Plastic Pipe in Industry" by P. A. Turner of Du Pont of Canada, Ltd., and "Properties and Applications of Plastic Materials" by C. A. Burt of American Hard Rubber Co.

Abstracts

A Generalized Description of Metallic Passivity, by N. D. Greene, Rensselaer Polytechnic Institute.
Describes metallic passivity, based on concept of mixed potentials and results of potentiostatic polarization measurements. Active-passive behaviors of iron, chromium, titanium and stainless steels are compared with their specific corrosion resistant properties. Extension of these results to prediction of new corrosion resistant alloys and to anodic protection techniques is discussed.

Derivation of Anodic Dissolution Curve of Alloys From Those of the Metallic Components, by W. A. Mueller, Pulp and Paper Research Institute of Canada.
Shows derivation of polarization curves of alloys from those of the single metallic components. Conclusions are corroborated by comparison with polarization curves of ferritic and austenitic stainless steels. Some features of the mechanisms involved in growth of passive films has been revealed. In active and passive states, the metal of lowest rate of dissolution controls the dissolution of the alloy if the alloy composition is selected properly.

Corrosion Resistant Equipment of Titanium, Zirconium and Tantalum, by Clifford A. Hampel, Skokie, Ill.
Gives detailed corrosion resistance properties of these metals and describes typical equipment which can be fabricated from them. All three metals become very reactive, in general, at temperatures much above about 150 C, with notable exceptions. All can be fabricated readily into a wide variety of equipment.

Outdoor Corrosion Tests in Canada, by E. V. Gibbons, National Research Council, Ottawa, Canada.
Describes atmospheric exposure program begun in 1950 to compare corrosion behavior of metals after exposure at several locations across Canada. Exposure sites and their facilities are described. Results are given after one, two and five years for several architectural metals, metal coatings and paint systems.

Corrosion of Domestic Hot Water Tanks, by P. J. Sereda, National Research Council, Ottawa, Canada.
Discusses corrosion of galvanized tanks studied in domestic installation in Canadian housing projects. With sample tanks used, temperature was an important factor affecting corrosion. With commercial tanks, use of a 3 kw side arm heater in place of the small immersion heater was the greatest single factor in reducing corrosion. Results from tests involving corrosion inhibitors was inconclusive, probably because the concentration of about 10 ppm was too low. Micrographs of galvanized coatings show that corrosion attack was irregular starting with fissures. These fissures appear even in uncorroded edges, indicating that they are produced during the galvanizing process and that changes in this process could improve corrosion resistance.

New Corrosion Resistant Coating for Mine Hoist Wire Rope, by W. Dingley, J. Bednar and R. R. Rogers, Department of Mines and Technical Surveys, Ottawa.
Presents results of an investigation of excessive corrosion on mine hoist wire rope. Includes description of type of deterioration, an outline of experiments in which commercial protective materials were used, description of investigation in which a new asphalt-zinc chromate coating was developed and gives data on performance of this coating in laboratory tests.

Officers Are Incorrectly Listed as Already Elected

The list of officers for the Canadian Region published on Page 68 of the September issue of CORROSION was in error: the slate of officers listed as being elected were the candidates named by the nominating committee. The slate will be voted on by mail ballots.

Northeast Region

Pittsburgh Section Plans All Programs for 1960-61

Plans have been completed for the 1960-61 programs for the Pittsburgh Section. A list of the dates and the programs scheduled are given below.

October 6: Combating Automobile Corrosion Problems Through Design, Special Processing and Materials, by Leonard C. Rowe, General Motors Corp.

November 3: Coatings Roundtable, Kenneth Tator, chairman.

December 1: Underground Roundtable: C. A. Erickson, chairman.

January 5: Corrosion in Nuclear Fields, by J. M. Williams, III, Avco Research and Advanced Development Co.

February 2: Aluminum in the Process Industries, by Ralph Horst and M. E. Carlisle of Aluminum Company of America.

March 2: Corrosion Problems in Navigation and Flood Control Structures, by M. V. Harrington.

April 6: Ladies' Night program.

May 4: Plant tour of the Duquesne Brewery and discussion of corrosion problems in the brewing industry.

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Kanawha Valley Section heard N. P. Peifer speak on cathodic protection interference problems at the September 22 meeting.

Lehigh Valley Section heard Earl Sorg of Thiokol Corporation speak on liquid polymer epoxy coatings at the September 19 meeting.

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Baltimore-Washington Section scheduled Leon S. Birnbaum of the Bureau of Ships to review the U. S. Navy tank coating program for the September 20 meeting.

•

Metropolitan New York Section heard J. R. Allen of du Pont discuss application tolerance of protective coatings for the September 14 meeting.

(Continued on Page 66)

SECTION CALENDAR

October
5 Teche Section. Petroleum Club.
10 Greater St. Louis Section. Alloys in Process Industries, by John Schley.
10 Kansas City Section.
10 Central Oklahoma Section.
10 North Texas Section. Cathodic Protection Studies, by A. R. Erben. Torch Restaurant, Dallas, 6:30 p.m.
11 San Francisco Bay Area Section.
11 Houston Section. Houston Engineers' Club.
11 Permian Basin Section.
18 Cleveland Section.
18 Alamo Section.
18 Southwestern Ohio Section. High Temperature Corrosion Problems in the Chemical Industry, by John R. Schley. To be held in Cincinnati.
20 Vancouver Section.
24 Tulsa Section.
25 Panhandle Section.
25 San Joaquin Valley Section. Maison Jaussard's Restaurant, Bakersfield, Cal.
25 Southwestern Ohio Section.
25 Genesee Valley Section. Discussion on Penton, by G. M. Taylor, Hercules Powder Co.

November
2 Teche Section. Petroleum Club.
4 Birmingham Section. Hydroelectric and Steam Plant Construction and Corrosion Problems, by R. S. Woodruff.
8 San Francisco Bay Area Section.
8 Houston Section. Houston Engineers Club.
8 Permian Basin Section.
14 Greater St. Louis Section. Roofing Materials for Chemical Plants, by C. R. Martinson.
14 Kansas City Section.
14 Central Oklahoma Section. Down Hole Corrosion, by W. C. Koger. Tropical Cafeteria, Oklahoma City.
14 North Texas Section. New Techniques of Inhibition in Producing Oil and Gas Wells, by D. R. Fincher.
15 Baltimore-Washington Section. Slide talk on 1960 NACE Conference by C. A. Muller.
15 Chicago Section. Tape Coating Forum and Panel.
15 Alamo Section.
15 Cleveland Section.
17 Vancouver Section.
28 Tulsa Section.
29 Panhandle Section.
29 Southwestern Ohio Section. Underground and Industrial Coatings, by W. E. Kemp. To be held in Cincinnati.

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Procedure in Selection of Persons to Receive Whitney and Speller Awards

Procedure in the Selection of Persons to Receive the Willis Rodney Whitney and Frank Newman Speller Awards as Approved by the Board of Directors, December 4, 1953 and Revised March 6, 1955 and December 7, 1957.

The Board of Directors of the National Association of Corrosion Engineers in a regular meeting on January 17, 1947 authorized the presentation annually of two awards by the Association:

The Willis Rodney Whitney Award is given in recognition of public contributions to the science of corrosion. A contribution to science is defined as the development of a more satisfactory theory which contributes to a more fundamental understanding of corrosion phenomena.

The Frank Newman Speller Award is given in recognition of public contributions to corrosion engineering. A contribution to engineering is defined as the development or improvement of a method, apparatus or material by which the control of corrosion is facilitated or made less costly.

Not later than January 1st of each year, the President in consultation with the immediate past President shall appoint an awards committee. This committee shall consist of at least six members with the President serving as Chairman. He shall continue to serve as chairman of the committee for the calendar year and shall present the award to the recipients selected by his committee. In the event the President upon becoming past President should be unable to serve, the President (for the year the award is to be made) shall appoint a Chairman. The other members of the committee should be outstanding members of the Association. Members shall be appointed for a three-year term with two members being replaced each year. Any member who is lost through resignation or for any other reason, shall be replaced by appointment by the President of the Association.

The Chairman of the Awards Committee shall arrange to keep reasonably detailed records of the activities and discussions of the Committee. These records shall be made available to succeeding Awards Committees.

The Awards Committee shall meet at the Annual Conference, or in the event the Annual Conference is not held or is held later than June 1st the Chairman shall conduct the committee business by correspondence.

The list of candidates to be considered for the Awards shall include:

A. The names of those proposed by the Chairmen of the Regional Divisions in accordance with the wishes of the members of the Division. Nominations may be made by local sections or may be proposed directly to the Chairman of a Region by individual members. In any case, nominations should be accompanied by an appropriate statement of the basis of the proposal. This statement shall be reproduced and submitted to all members of the Awards Committee. The Committee should have such statement for all nominees to be considered.

Prior to February 1st of each year the Regional Chairman shall forward to the Executive-Secretary all names proposed for awards, accompanied in each case by summaries of the reasons presented in support of each proposal but with no indication of the number of duplicate nominations of any individual. The object of this latter provision is to insure that awards will be made on a basis of accomplishments and other qualifications rather than by any semblance of a popular vote.

Not later than October 1st (or the publication date of the October issue of CORROSION of each year the Executive Secretary shall notify the membership through publication in CORROSION of their privileges in this regard as set forth here. A similar notice shall be mailed by direct letter to all region and section chairmen by October 1st.

B. Any names proposed by the members of the Committee prior to February 1st of each year.

C. The Committee may review and consider nominees from previous years.

D. All nominations shall be submitted to the Executive Secretary who shall distribute copies to all members of the Committee. Nominations will be closed on February 1st.

At the discretion of the Committee members the resultant list of candidates may be reduced to a workable number by elimination of those known to lack the necessary qualifactions.

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As a basis for further consideration by the Committee, the headquarters staff of the Association shall provide the Committee, through its Chairman, with a record of the contributions of each final candidate in the form of a list of his published papers and other works. Such records available in the headquarters office may be supplemented by additional information on the candidates' qualifications which may be secured by any member of the Committee from other sources, such as friends of the candidates, and especially from the proposers of the candidates who should be asked to provide their reasons for suggesting them and a summary of their accomplishments. Ordinarily, the candidates should not be made aware that they are being considered for awards by seeking such information from them directly.

The required activity of the headquarters staff should be facilitated by appropriate use of the literature abstract filing system.

The list of candidates about whom the headquarters staff is to provide the information described should be sent by the Chairman of the Committee to the Executive Secretary of the Association and to each member of the Committee not later than May 1st.

The information to be provided by the headquarters staff should be sent by the Executive Secretary to the Chairman and each member of the Committee not later than July 1st.

Information secured by any member of the Committee concerning any candidate or candidates should be sent to the Executive Secretary not later than June 15th so that it can be circulated amongst all the members of the Committee not later than July 1st.

Not later than August 1st, each member of the Committee shall submit to the chairman and by copy to each member of the Committee his first and second choice nominations for each award and shall provide with his nominations, his appraisal of the qualifications of those he is nominating and his reasons for preferring them. If a member of the Committee feels that no award should be given, he should so state by August 1st. Failure to nominate either a first or second choice for either award will not relieve a committee member of the duty of voting on the nominations made by others, or of voting that no award be made if those nominated are not considered satisfactory.

Notes for Guidance Of Awards Committee

A. The Committee shall not recommend the same individual for both awards in in any one year.

B. Previous recipient of an award is not eligible to receive the same award again.

C. The recipient of one award is not barred from receiving the other award for some other year.

D. In considering the qualifications of those nominated for awards, the nominee's total contributions should be taken into account and recent activities should not take precedence over the recognized results of eariler work. Other things being equal, awards should be made to the candidates who have been contributing consistently for the longest period.

E. Candidates need not be residents of North America.

F. Candidates need not be members of the National Association of Corrosion Engineers.

G. Awards shall be limited to living persons.

H. Recipients of the Willis Rodney Whitney and the Frank Newman Speller Awards and the recipient or recipients of the Junior Award should be guests at the annual NACE banquet.

I. The President and Vice President of the Association and the Chairman of the Awards Committee should not be considered as candidates for awards.

February 27, 1958

Between August 1st and September 1st, the Chairman shall arrange for a letter ballot election by the Committee of those to be nominated for the Awards. If no decision can be made by the first ballot, then a second ballot shall be taken on those who have received the most and and second most votes on the first ballot. In the event of a tie for first place on the first ballot, only those names shall be considered in a second ballot. Similarly, in the event of a tie for second place these names, plus the first place name, shall be considered on a second ballot. In the event a person is nominated for both awards, his vote for one award shall not be considered in determining his standing in the vote for the other award.

If the Committee should decide that none of those nominated are worthy of the Awards, or if no nominations are received, the Committee may recommend to the Directors that one or both Awards be withheld for reasons to be stated in their report to the Directors.

Recommendations of the Committee shall be reported by the Chairman of the Committee to the Board of Directors through the Executive Secretary not later than November 1st.

In the event that the Committee should be unable to reach a decision on candidates for either or both awards, the Committee shall provide the Board with a list of all those proposed for consideration and the number of votes received by each on the last ballot of the members of the committee.

The Board of Directors shall then determine, either in a regular meeting, or by letter ballot, returnable not later than December 1st in each year, whether the recommendations of the Awards Committee are to be accepted and the awards made as proposed. If the Board of Directors do not approve the granting of an award or awards, as proposed by the Awards Committee, then such award, or awards, will not be made for the year in question. In the event that the awards committee has been unable to reach a decision on candidates for one or both awards, the Board of Directors shall determine by majority vote whether an award (or awards) shall be made and to whom it (or they) shall be granted.

After the Board of Directors have chosen the recipients of the awards, the President of the Association shall notify the recipients not later than December 15th, and shall invite each of them to be present at the annual meeting or other occasion when the awards are to be presented. The Chairman of the Committee shall arrange to have appropriate certificates inscribed for presentation to the recipients of the awards and on occasion of any public presentation of the awards he shall present the recipients to the President or whoever may be serving in his stead as Chairman of the meeting, to receive the awards at his hands.

The actions of the Awards Committee shall be confidential and confined to consideration only as outlined in the procedure until such time as the President receives acceptance or rejection from the awardees following his notification to them. After receiving acceptance of an award or awardee, the President shall so notify the Executive Secretary who may publicize the information prior to the actual presentation of the award or awards.

Northeast Region

Schenectady-Albany-Troy Section Plans Meetings

Three meetings to complete its 1960 calendar have been set and programs planned by the Schenectady-Albany-Troy Section. The meetings are set for October 12, November 9 and December 7. No meeting will be held in January. Programs for the 1960 meetings are given below.

October 12: R. J. Schmitt of U. S. Steel Applied Research Laboratory will discuss use of iron, low carbon and alloy steels in the chemical industry.

November 9: Norman Hackerman of the University of Texas will give a paper on "Status of Corrosion Inhibitor Studies and Test Programs."

December 7: W. E. Ray of Dresser Products Co., Barrington, Mass., will discuss corrosion problems of reactor core materials in pressurized water reactors.

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NACE Certificates of Membership are available from the Central Office. Measuring 5½ x 8½ inches, the certificates cost $2 each and are signed by the association president and executive secretary.

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Certificates for past chairmen of regions and sections, measuring 9 x 12 inches, are available from the Central Office at $7.50 each.

CORROSION ABSTRACTS

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4. CORROSIVE ENVIRONMENTS

4.2 Atmospheric

4.2.3, 5.9.4, 5.8.1

A Review. The Residual Oil Ash Corrosion Problem. C. J. Slunder. Corrosion, **15,** No. 11, 601t-606t (1959) Nov.

Progress being made in combating accelerated high-temperature corrosion caused by combustion products of residual fuel oils is reviewed. Results of laboratory investigations cannot be compared strictly because of wide differences in testing procedures used. No effective and economical method for removing all offending ash components has been found, although lowering of sodium content by washing with magnesium sulfate solution has been applied successfully to gas turbine operating. Available high-temperature alloys do not have adequate resistance to oil-ash attack at temperatures above 1200 F. Improved corrosion resistance has been attained with certain experimental alloys but some of these are difficult to fabricate into the required form and have inferior mechanical properties. Surface treatments such as aluminizing, chromizing and siliconizing appear to have some inherent protective value, but further development of procedures for applying impervious and adherent coatings is needed.

Investigation of oil additives has received the most attention in recent years. A great many inorganic, or metal-organic compounds are effective oil-ash corrosion inhibitors but only a few have been found to be economically feasible. Additives raise melting point of ash components so they will be solid at operating temperatures in boilers and gas turbines. Under certain conditions some additives reduce corrosion but increase deposit formation.

Progress is being made in basic studies to identify reactions taking place during combustion of oil and in application of this knowledge to establish mechanism of the corrosion reaction. 19515

4.2.3, 7.6.4

Prevention of Steel Stack Corrosion and Smut Emission with Oil-Fired Boilers. H. A. Blum, B. Lees and L. K. Rendle. J. Inst. Fuel, **32,** No. 218, 165-171 (1959) April.

Stack corrosion and smut emission in oil-fired boilers were studied. To reduce heat losses, the steel stack of a 6000 lb. lb./hr. boiler was fitted with an aluminum shield and a 0.25 in. air gap was left. Temperature distribution in the stack and the emission of smuts was determined with and without the shield. The smuts are caused by an acid solution which deposits from the flue gases on cool steel surfaces and forms iron sulfates. The shield raises the temperature of the stack well above the acid dewpoint. 18215

4.2.3, 4.4.9

Corrosion of Metals Exposed to Combustion Gases Below 400 F. Paul D. Miller. pp. 169-184 of "A Review of Available Information on Corrosion and Deposits in Coal- and Oil-Fired Boilers and Gas Turbines," 1959. Available from The American Society of Mechanical Engineers, 29 West 39th Street, New York 18, New York.

Pertains to the corrosion of metals by the acids of S; attention is also given to the possible action of HCl and to N oxides. Knowledge on methods for reduction or elimination of the corrosive attack on S acids is discussed for many studies established definitely that sulfuric acid formed by the oxidation of the S present in commercially available fuels is the principal cause of the corrosion of metal surfaces in the sections of fuel-burning equipment that reach temperatures below 400 F.—BTR. 19329

4.2.1

Corrosion Resistance of Metals Under Atmospheric Conditions. (In Czech.) K. Smrcek. Korose a Ochrana Materialu, **3,** No. 1-2, 1-4, (1959).

Corrosion resistance of combinations of Fe, Cr, Ni, Al, Zn, Cd, Ag, Cu, Sn and Mg influenced more by atmospheric conditions than by electrochemical relation of the combined metals. Magnitude of Cu corrosion in combination with Ni, Cd, Sn, Zn or steel was determined at 3.5 g/cm^2 per day.—RML. 19487

4.2.3, 3.5.9, 4.3.3, 6.2.1

High Temperature Corrosion Resistance of Steels on Fuel Oil Ash. (In Japanese.) T. Obata, Y. Morishita and H. Iijima. J. Chem. Soc., Japan, Ind. Chem. Sect., **61,** No. 10, 1228-1230 (1958) Oct.

A study was made on high-temperature corrosion resistance of steels in contact with V_2O_5, or synthetic ash (V_2O_5 66.6 per cent, Na_2SO_4 19.9 per cent, NaCl 3.0 per cent, $CaSO_4$ 2.0 per cent, NiO 5.2 per cent, Fe_2O_3 1.8 per cent, Al_2O_3 1.5 per cent). Corrosion resistance improved as chromium content increased, but decreased as molybdenum content increased. Micro-structure was not affected by contact with fuel oil ash and intergranular corrosion was observed only in one case. MgO and $MgSO_4$ had equal inhibitive effects. —JSPS. 19381

4.2.7, 5.3.2, 6.2.5, 5.9.4

Corrosion Tests Simulating the Conditions of a Tropical Climate. (In Russian.) I. I. Pomerants and A. I. Rivlina. Vestnik Elektroprom., No. 6, 62-65 (1958).

Protected and unprotected metal parts were tested for 18 hrs. at 43-47 C and 95-98 per cent relative humidity, followed by 6 hrs. at normal temperature and humidity. Surface roughness rapidly initiated corrosion and was particularly harmful where steel parts were plated with Cu/Ni/Cr or Cu/Cr. 18:8 stainless steel was more resistant when electropolished. Passivation solution containing Na_2CrO_7 25, Na_2SO_4 20 g/l, HNO_3 20 ml gave better protection than Na_2CrO_7-H_2SO_4 solution to Cd plating; additional protection was obtained by degreasing and coating with spindle oil or BF-2 glue. Various electrodeposited coatings were found unsatisfactory for use on TB-3 and TB-4 bimetals, because of changes in electrical resistance (ρ); chem. Ni coatings were satisfactory as deposited, but ρ fell by up to 28 per cent on heating at 170-450 C., apparently owing to changes in the composition and structure of the Ni-P layer. Varnish coatings behaved well. Passivation in CrO_3 solution was found superior to chem. Ni or electrodeposited Sn or Ag for protecting flexible Cu wire. Constructional materials suitable for tropical use are listed.—MA. 19405

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4.2.1, 2.2.2, 2.3.2, 5.4.5

Research on the Influence of Climate on Paints. M. A. Arnan and C. Shatil. Booklet, 1959, 90 pp. Standards Inst. of Israel. (In Hebrew with English Summary.)

Natural weathering of a range of building paints at five sites representing typical Israeli climates was compared with accelerated weathering and salt spray tests. The best weathering performance was found in the coastal areas and the worst inland in Jerusalem and Beer-Sheba, failure being associated with strong ultraviolet irradiation at Jerusalem and sand erosion at Beer-Sheba. Synthetic paints behaved better than oil paints and more breakdown occurred on wood than on hardboard or plywood panels. Accelerated weathering tests correlated with natural exposure at the coastal sites but not inland. Salt spray corrosion resistance tests showed fair correlation with exposure at Haifa, 5 meters from the sea, but little correlation at Le-Avib, 2000 meters from the sea, and none at Beer-Sheba.—RPI. 19649

4.2.1, 5.3.2

Climatic Demands and Surface Protection. (In German.) H. Burchard. Metall, **13**, No. 6, 526-536 (1959) June.

This is a very detailed review of protective metals. Eight climatic regions are shown on a map and tables give their air temperatures, humidities, surface temperatures and other characteristics. Protective metals are then classified and tables give specifications and thicknesses for the various climatic conditions. 3 figures, 8 tables, 6 illustrations. —ZDA. 19715

4.7 Molten Metals and Fused Compounds

4.7, 6.4.2, 6.3.20, 6.6.4, 8.4.5

Resistance of Barrier Materials to Sodium Jet Impingement. Nuclear Development Corp. of America. U. S. Atomic Energy Commission Pubn., NDA-084-4, Feb. 26, 1958, 48 pp. Available from Office of Technical Service, Washington, D. C.

Preliminary screening tests were made with several materials to provide an index of their suitability as barrier materials for use in the SDR. The tests were made by directing a jet of sodium through a 3/32-in. diameter nozzle at uncooled 2 in. by 2 in. plate specimens; the sodium jet conditions included temperatures from 950 to 1140 F, velocities up to 50 fps, and impingement times ranging from 15 min. to 18 hr. A summary of tests made and their results is presented. It was found that Al performed well in these tests. No failure of samples having practical thicknesses occurred at 950 F in tests which ranged up to 18 hr. Failure was finally effected at 950 F with a 5-mil aluminum sample. It was found that 0.060 in. aluminum plate also performed well at 1050 F; the maximum test time at this temperature was 3½ hr. One sample was tested at 1140 F and lasted for the length of the test (15 min.), but one sample tested at 1100 F failed after 3 hr. (Maximum Na temp. expected in the SDR is 1025 F.) Zr and steel performed well. While graphites in general performed poorly, AGOT-type (reactor grade) performed well enough to indicate that it may be developed into a suitable high-temp. barrier. (auth.) —NSA 19339

4.7, 6.3.10, 6.2.5, 3.2.2

Corrosion by Liquid Metals and Aqueous Solutions. P. H. Eisenberg. pp. 47-62 from "Metals for Nuclear Reactors". Book, 1959. American Society for Metals, Metals Park, Novelty, Ohio.

Mass transer and intergranular penetration in corrosion of Inconel and stainless steels by liquid metals. Reaction of impurities in liquid metal and purification techniques. Intergranular corrosion, stress-corrosion cracking and galvanic corrosion of stainless steels by aqueous solution at high temperatures. Static and dynamic testing.—RML. 19772

4.7, 6.3.17

Dissolution Rate of Uranium in Liquid Metals. G. J. Segre. Comitato Nazionale per le Ricerche Nucleari, Milan, Italy. June, 1959, 11 pp. On Deposit at the Depository Libraries. Microcards available from Microcard Foundation, 901 26th St., N.W., Washington 7, D.C.

At 356 C the rate of dissolution of uranium in boiling mercury saturated with uranium decreases with increasing contact time, presumably due to the formation of a mercurish film. Initial rates as high as 30 $\text{mg/cm}^{-2}/\text{hr}^{-1}$ and final rates as low as 0.5 $\text{mg/cm}^{-2}/\text{hr}^{-1}$ were observed. In uranium-saturated molten bismuth at 400 C the corrosion rate is 28 $\text{mg/cm}^{-2}/\text{hr}^{-1}$ and is essentially independent of exposure time. (auth)—NSA. 19476

4.7, 6.3.9, 6.3.13, 6.3.5

The Compatibility of Molybdenum, Tantalum and Niobium with Liquid Bismuth and Bismuth-Uranium Solutions. (In English.) E. D. Lloyd. Plansee Proc. 1958, **1959**, 249-256. Available from Metallwerk Plansee A. G., Reutte/Tyrol, Austria.

Tests were carried out at 700-1000 C mainly under static conditions, the liquid metal being contained in a crucible of the material under test. Molybdenum was also tested in liquid bismuth under dynamic conditions by circulating liquid bismuth in a molybdenum tube inserted in a quartz thermal-convection loop. Tantalum and molybdenum show good resistance to static bismuth-uranium solution up to 800 C. Niobium showed poor resistance to liquid bismuth at 1000 C. In the dynamic test, molybdenum showed good resistance to thermal-gradient mass transfer in liquid bismuth at low flow rates.—MA. 19275

5. PREVENTIVE MEASURES

5.2 Cathodic Protection

5.2.1, 8.4.3

Mitigation of Casing Corrosion in Gas Storage Wells. Y. W. Titterington. Paper before AGA, Transmission Conf., Dallas, May 18-19, 1959. Gas Age, **124**, No. 5, 22-29 (1959) Sept. 3.

Cathodic protection is described as providing a field-tested solution to corrosion problems in storage wells. Causes and detection of corrosion are covered, as well as current requirements and application of cathodic protection. External corrosion of well casing may be caused by one or more of following factors: galvanic cell action between casing and surface piping; galvanic cell action between formation strata; anaerobic sulfate reducing bacteria; chemical attack by acidic waters; or stray current electrolysis. Galvanic type action usually produces most pronounced effect. Casing potential drop log method of detecting corrosion and of determining current requirements, and log current-potential method of determining current requirements are described. Diagrams, graphs. —INCO. 19573

5.2.1, 4.6.11, 8.9.3

Cathodic Protection of Marine Pipelines. (In Russian.) M. S. Trifel, V. F. Negreev and S. A. Mekhmandarov. Stroitel Truboprovodov (Pipeline Construction), **4**, No. 8, 4-7 (1959) Aug.

To prevent corrosion of steel pipelines in sea water, either the potential must be made 0.15 v. more negative, or a protective current density of 0.15 amp/sq m must be applied to the pipeline. The second method can be used only to protect uninsulated pipelines in cathodic protection under water the negative displacement of the potential continues long after the protective current has been switched off, owing to deposition of magnesium and calcium salts on the steel surface. Underwater protection can therefore be applied intermittently (one month on and two months off), cutting the consumption of anodes and electrical power by two-thirds. 19547

5.2.2, 7.10

Cathodic Protection for the Kojima Lake Gates. (In Japanese.) Eiji Fukutani and Hisahiko Osato. Corrosion Engineering, **9**, No. 2, 49-51 (1960) Feb.

The Kojima Lake is an artificial lake. The bank was built at the narrowest point of the Kojima Gulf and it separates the sea and the lake. There are 12 watergates and one set of lockgates. The gates were painted by vinyl paint 3 years ago. The paint is deteriorated to some extent, and rust was found from place to place. The gates are now protected by sacrifiical anodes. The lockgates are opened ~ 30 to 40 times daily and several watergates are opened daily for a few hrs. to adjust the lake water level. Therefore, polarization of gates will be interrupted quite frequently. The resistivity of lake water is affected by many factors, i.e. season, weather, water depth, duration and frequency of gate opening, leakage rate of the gates, etc. Zinc anodes are used in the sea and in the lock chamber, and magnesium anodes are used in the lake. Protective current density is 40 mA/m^2 and designed potential of the gates is —900 mV referred to S.C.E. Satisfactory results are obtained in the seaside, but minimum protective potential of —770 mV referred to S.C.E. is maintained in the lock chamber and in the lake. 19151

5.2.3

The Permanent Anode in Impressed-Current Cathodic Protection Systems. Parts 1, 2. C. A. Curtis. Corrosion Technology, **6**, Nos. 10, 11, 296-298; 333-334, 342 (1959) Oct., Nov.

Describes manufacture, properties, uses and limitations of principal materials used as anodes in impressed current cathodic protection systems, together with some indication of effects of different environments upon these materials. Graphite, silicon, iron, scrap steel, lead, platinized lead, and platinized titanium are covered. Fundamental principles of connection are also considered. Tables, graphs, diagrams, 5 references.—INCO. 19060

5.2.3, 6.2.2, 4.6.11

Use of Titanium and Titanium Alloy Anodes for Impressed-Current Cathodic Protection. (In French.) H. Richaud. Corrosión et Anticorrosion, **7,** No. 9, 322-324 (1959).

The best results were obtained with Ti-Mn alloys, which are particularly suitable for protection of Fe in seawater. Their application is, however, limited to c.d. of ~10 m.amp/dm^2, above which localized corrosion occurs. For high anodic c.d., platinum-plated titanium should be used.—MA 19442

5.2.1, 3.8.2, 3.8.3

Cathodic Protection and Its Applications in the Maritime Field. (In French.) B. Raclot. Corrosion et Anticorrosion, **7,** 342-355 (1959) Oct.

Theoretical considerations on the corrosion behavior of a metal immersed in an electrolyte and its state of passivity or immunity. Cathodic protection by sacrificial anodes or by connecting the part to be protected to a chemically inert anode.—RML. 19410

5.2.3, 3.6.3, 4.5.1

Cathodic Protection of Steel in a High-Resistivity Environment. National Bureau of Standards. Technical Rept. STR-2410, Dec., 1959. Available from NBS, Office of Technical Information and Office of Technical Services, Washington, D. C.

When cathodic protection against corrosion is employed for steel structures, such as pipelines, in a high-resistivity soil, the potential should be maintained at −0.77 volt, with reference to a saturated calomel electrode. Furthermore, to achieve the best results in mitigating local action corrosion, IR (voltage) drop between metal and reference electrode, caused by the externally applied protective current, should be excluded from potential measurements. These conclusions were drawn from a National Bureau of Standards experiment, carried out under laboratory conditions. 19355

5.2.3, 4.6.7, 4.6.3

Second Interim Report on Use of High Silicon Cast Iron for Anodes. Report of NACE Technical Unit Committee T-2B on Anodes for Impressed Currents. Pub. No. 59-16, 12 pp., July 1, 1959. National Association of Corrosion Engineers, 1061 M & M Building, Houston 2, Texas.

Data from more than 250 separate installations are collected, analyzed and tabulated, continuing information presented in the first interim report. Considered separately are ground beds, fresh water service and salt water service. The report says data support earlier evidence that corrosion of anodes is negligible in coke breeze backfill. Service in fresh water is generally good except at temperatures in the 160-200 F range. Molybdenum appears to have effect of extending service life.

In salt or brackish water evidence indicates that molybdenum additions are beneficial in extending life, especially at higher temperatures. Regular high silicon anodes are not recommended for use in low resistivity salt water. 19349

5.2.3, 4.6.7, 4.6.3

Third Interim Report on Use of High Silicon Cast Iron for Anodes. Report of Technical Unit Committee T-2B on Anodes for Impressed Current. Pubn. No. 57-17, 13 pp., July 1, 1959. National Association of Corrosion Engineers, 1061 M & M Building, Houston 2, Texas.

Reports of data received in reply to questionnaires circulated by Task Group T-2B-4 during 1957 are reported. Data show no appreciable difference exists in performance of high silicon cast iron and graphite in a well tamped coke breeze backfill. Results indicate high silicon iron possesses excellent resistance to various fresh water under normal temperature conditions. High silicon iron containing molybdenum shows better performance than regular alloy under adverse salt water conditions.

General results of this survey are divided into three groups: ground bed, fresh water and salt water applications. Tables are included giving typical installations for each group. 19350

5.2.1, 8.4.3, 2.4.2

Cathodic Protection of Storage Well Casings. W. R. Lambert and G. G. Campbell. Paper before Am. Petroleum Inst., Div. of Production, Pittsburgh, April 8-10, 1959. Gas Age, **124,** No. 1, 21-24 (1959) July 9.

Discussion of cathodic protection of underground storage facilities, with conclusions based on tests made on well casings and field gathering lines of United Fuel Gas Co. A probe for making potential drop measurements was designed during 1955 and 1956. It consisted of 2 sets of contacts that could be spaced at predetermined intervals by selection of proper length of divider pipe. Contact points were made of steel with Stellite facing, and were fastened to contact springs made of spring steel. Four field tests have been made to date with this probe; results are described. It may be common practice in near future to apply a protective coating to casing before it is put into ground. United Fuel Gas Co. has already taken a step in this direction. Use of either anodes or rectifiers for cathodic protection will be dependent upon conditions in particular well or field under investigation.—INCO. 19277

5.2.3, 8.9.5, 1.2.2

Nonsacrificial Lead Anode for Corrosion Control in Water. Lead, **22,** No. 4. 4-6 (1958).

Lead alloy anodes are economically and technologically superior to graphite, steel, platinum, or magnesium anodes for impressed current cathodization. The anodes and mountings can be easily applied to any ship or marine structure, have an almost indefinite life, and offer little resistance to a ship's movement through water. The approved anodes are made of extruded lead alloyed with 6 percent antimony and 1 percent silver or 98 percent lead and 2 percent silver. The hull of a destroyer equipped with such anodes was rust-free after two years. The cost of the anode system was about $890 per year compared with $2018 per year for a magnesium system, and $3813 for a steel system. 19279

TECHNICAL REPORTS on PIPE LINE CORROSION

T-2 Statement on Minimum Requirements for Protection of Buried Pipe Lines. Prepared by a Special Task Group of NACE Technical Group Committee T-2 on Pipe Line Corrosion. Publication No. 56-15. Per Copy $1.50.

TP-2 First Interim Report on Galvanic Anode Tests. (Pub. 50-2) NACE members, $3; Non-members, $5 Per Copy.

TP-3 First Interim Report on Ground Anode Tests. (Pub. 50-1) NACE members, $3; Non-members, $5 Per Copy.

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T-2B-4 Fourth Interim Report on Use of High Silicon Cast Iron for Anodes. A Report of Technical Unit Committee T-2B, Prepared by NACE Task Group T-2B-4 on High Silicon Cast Iron Anodes. Publication 60-3. Per Copy $1.50.

T-2C Some Observations of Cathodic Protection Potential Criteria in Localized Pitting. A Report of T-2C on Minimum Current Requirements for Cathodic Protection. Pub. 54-2. Per Copy $1.50.

T-2C Some Observations on Cathodic Protection Criteria. A contribution to the work of NACE Technical Unit committee T-2C. Publication No. 57-15. Per Copy $2.00.

T-2C Criteria for Adequate Cathodic Protection of Coated, Buried, Submerged Steel Pipelines and Similar Steel Structures. A Report of NACE Technical Unit Committee T-2C on Criteria for Cathodic Protection. Pub. 58-15. Per Copy $1.50.

T-2D Methods for Measuring Leakage Conductance of Coating on Buried or Submerged Pipe Lines—A Report of Tech. Unit Committee T-2D on Standardization of Procedures for Measuring Pipe Coating Leakage Conductance. Pub. 57-27. Per Copy $1.50.

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T-2H Second Interim Report. Tentative Recommended Specifications for Asphalt-type Protective Coatings for Underground Pipe Lines—Mastic Systems. A Report of NACE Technical Unit Committee T-2H on Asphalt-type Pipe Coatings. Publication No. 57-14. Per Copy $1.50.

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·5.2.2, 1.2.2, 8.9.5

Interior Protection of Tankers Against Corrosion. (In Russian.) L. N. Andryu shkina. Sudostronenie, No. 6, 48-49 (1959).

The economic advantage of sacrificial anodes in protecting ships against corrosion is clearly shown by calculations. A system of anodes for protecting the interior surface of the tanks and the exterior of the hull will protect more than 80 per cent of the ship's body against corrosion. The most effective system for tankers is the two-stage system which consists of main electrodes and a large number of auxiliary electrodes of large surface area. The auxiliary and the main electrodes may be combined into a single assembly. 19639

5.2.2, 6.2.2

Cathodic Protection with Zinc as Active Anode. (In German.) E. Eberius and H. Bohnes. Metall, **13,** No. 8, 743-746 (1959).

The use of zinc sacrificial anodes for iron is discussed. The effect of the area ratio, ventilation and circulation of the 3.5 per cent NaCl electrolyte was investigated. The composition of the zinc anode is also discussed in detail. 5 figures.—ZDA. 19770

5.3 Metallic Coatings

5.3.4

Hot Dip Galvanizing: New Knowledge and Results. (In German.) H. Bablik. Osterreichische Ing. Z. (Austria), **1,** 91-96 (1958) Feb.

Topics discussed include the iron-zinc alloy formed in galvanizing, the influence of aluminum, the connection between immersion time and strength of coating, and factors affecting the rate of corrosion. Corrosion due to sulfur fumes is more severe during the winter months and in the dark. 7 figures, 12 tables.—ZDA. 19636

5.3.4, 6.3.9, 3.5.9

Protection (by Electrodeposition of Chromium/Nickel) of Molybdenum from Oxidation at Elevated Temperatures. Dwight E. Couch, Harold Shapiro, John K. Taylor and Abner Brenner. J. Electrochem. Soc., **105,** No. 8, 450-456 (1958). See also: Corrosion, **15,** No. 5, 110 (1959) May.

After electrodeposition of 0.001 in Cr/0.007 in. nickel, molybdenum samples were exposed under oxidizing conditions at 980, 1100 and 1200 C for 1200, 500 and 100 hours, respectively. Samples tested at 120 C failed rapidly, and at 1000 C the results were very variable. Shot peening and ball-milling of the deposits did not improve the life. Oxidation and diffusion both contribute to failure. 16 references.—MA. 19705

5.3.2, 8.9.1

The Cadmium Plating of Aircraft Components. L. Ades. Efco-Udylite Review, **1,** No. 3, 26-27 (1959) Mar.

Cadmium plating of aircraft parts presents many problems which are very difficult to solve, due to the nature and complexity of the articles. Initial unsatisfactory plating led to the adoption of a much more thorough cleaning system, and to de-embrittlement for three hours at 200 C after simple passivation in a sulfuric-chromic acid bath. After de-embrittlement the articles were washed in water then chromated with a Cronak-type solution.—ZDA. 19625

5.3.4, 8.4.5

Proposed Experimental Apparatus Design and Procedures for Vapor Phase Plating. J. Bodine. Atomic International Div., North American Aviation, Inc. U. S. Atomic Energy Commission Pubn., NAA-SR-Memo-4209, July 31, 1959, 36 pp. Available from Office of Technical Services, Washington, D. C.

It has been proposed to clad uranium-10 weight percent molybdenum and other reactor fuels with molybdenum, chromium and/or other metallic films by vapor phase plating. An apparatus was designed for plating uranium-10 wt. percent molybdenum fuel slugs ¾-in. diameter by 6-in. long, by thermal decomposition of a metal carbonyl. The first trial of the experimental investigation will be the plating of molybdenum from its carbonyl, $Mo(CO)_6$.—NSA. 19647

5.3.4, 6.3.17, 4.6.2, 8.4.5

Electroplated Metals on Uranium. J. G. Beach, W. C. Schickner, C. R. Konecny and C. L. Faust. Battelle Memorial Inst. U. S. Atomic Energy Commission Pubn., BMI-912 (Del.), May 7, 1954 (Declassified with deletions June 18, 1959), 33 pp. Available from Office of Technical Services, Washington, D. C.

Electroplating on uranium is being studied in connection with the development of an improved, slug-type fuel element for the Hanford Reactors and an aluminum-clad, flat-plate fuel element for the Savannah River Reactors. Four factors were found to influence the corrosion protection of uranium by electroplated metals: uranium surface preparation, method of electrodeposition, type and thickness of electroplated metal and conditions of heat treating required to surface alloy the composite. The alloy-coated uranium resists corrosion in boiling water for periods from 100 to 1000 times that of bare uranium. Hot-water attack of this alloy-coated uranium is generally localized as pit-type corrosion at areas of defects originating in the uranium metal. Thin as-deposited metals on uranium offer little or no corrosion resistance. Heat treatment of aluminum, chromium, copper, manganese, tin, or zinc-plated uranium did not provide corrosion resistance. (auth)—NSA. 19677

5.3.4, 6.3.17, 4.6.2

Electrodeposition of Nickel on Uranium. A. P. Beard and D. D. Crooks. Knolls Atomic Power Lab. U. S. Atomic Energy Commission Pubn., KAPL-1181, August 31, 1954 (Declassified November 30, 1959), 34 pp. Available from Office of Technical Services, Washington, D. C.

Electrodeposited nickel coatings on uranium for protection from destructive corrosion in boiling water was investigated. Correlation between the pretreatment of the uranium and subsequent protection by thin nickel coatings was established. Thin electrodeposited nickel coatings provide better protection when applied to a matte surface produced by blasting with an aqueous suspension of silica (100 mesh) followed by a cathodic treatment in 35 wt. percent sulfuric acid than when applied to the rough surfaces produced on uranium by anodic pretreatments and acid pickling. Blistering of nickel electrodeposits arising from hydrogen was encountered and eliminated. (auth)—NSA. 19685

5.3.4

Hot Dip Galvanizing. Erling Braaten. Teknisk Ukeblad, **106,** No. 36, 789-797 (1959) October 1.

Statistical review of zinc production and hot dip galvanizing in Norway. Corrosion problems and protection of steel by galvanizing. Review of the metallurgy of hot dip galvanizing and how the physical properties of steel under certain conditions can be changed by galvanizing. Summary of standard specifications.—BTR. 19694

5.3.4, 2.2.2

Outdoor Corrosion Results with Chromium-Nickel-Chromium Plate. H. Brown and M. Weinberg. Paper before Am. Electroplaters' Soc., Golden Jubilee Conv., Detroit, June 15-19, 1959. Tech. Proc. Am. Alectroplaters' Soc., **46,** 128-132; disc. 367 (1959).

Excellent corrosion protection results obtained in outdoor exposure in industrial atmosphere for plating sequence of Cr-Ni-Cr plate, Cu-Cr-Ni-Cr plate and Ni-Cr-Ni-Cr plate on steel and Zn diecast are detailed together with plating procedures used. Results are compared with Cu-Ni-Cr and Ni-Cr plates of various thicknesses. Types of corrosion pits encountered are compared and illustrated. Systems in which high temperature type of Cr plate was used beneath Ni plate in thicknesses of about 0.05 mils of Cr gave outstanding outdoor corrosion protection even after 3 years exposure in Detroit. Underneath Cr tends to divert corrosion pits laterally in Ni instead of allowing downward penetration into basis metal. Photomicrographs, 6 references.—INCO. 19693

5.3.2, 6.3.9

Oxidation Protection of Molybdenum Alloys with Reference to Their Application in Turbine Units. (In German.) H. Buckle. pp. 151-174 of "Plansee Proceedings—High Melting Metals" 1958 (Pubn. 1959). Metallwerk Plansee AG., Reutte/Tyrol, Austria.

Oxidation protection by nonmetallic coatings or by Ti, Pt, Cr and complex metal platings obtained by spraying, dipping and vapor deposition. 30 references.—RML. 19714

5.3.4, 5.4.5, 4.6.11, 8.9.5

Protection by Metal Spraying of Steel Ships Against Sea-Water and Electrolytic Corrosion. (In French.) Manley H. Clark. Paper Presented at Internat. Conf. Assoc. Metal Sprayers, Birmingham 1958. Corrosion et Anti-Corrosion, **7,** No. 7/8, 294-297 (1959.)

Practical and test experiences demonstrating the efficiency of sprayed zinc coatings covered by an organic paint are quoted. Aluminum coatings under polyvinyl paints give excellent protection against the effects of marine and industrial atmospheres and intermittent immersion in sea-water.—MA. 19722

5.4 Non Metallic Coatings and Paints

5.4.5

Primers for Protection of Metals Against Corrosion. A. Tarbouriech. Ann. Inst. Bâtim, **11,** No. 129, 947-952 (1958).

A general discussion of the properties and effectiveness of priming coats based on red lead, ferriferous or aluminous pigments, zinc chrome, aluminum or zinc powder. Experience shows that these paints behave differently and can be used to satisfy specific requirements.—RPI. 19578

5.4.5

Ten Painting Reminders for Steel Plants. W. T. Yarhouse. Iron Steel Eng., **35,** 129-141 (1958).

Ten considerations covering the selection, preparation, application and conditions of use of paint in steel plants are discussed. An appendix deals with common finishing troubles and defects and their correction.—RPI. 19618

5.4.5, 5.7.6

Permeability to Ions of Paint Films. K. Barton, D. Cermakova and E. Beranek. Werkstoffe u. Korrosion, **9,** No. 8/9, 519-521 (1958).

The addition of ion exchange resins to conventional film primers was studied as a means of preventing diffusion of corrosion-promoting ions to the metal substrate. Two materials were used, in granular form, for incorporation in alkyds, viz., a phenol polycondensate resin with ω sulphonic groups (cation exchanger) and a m-phenylenediamine resin (anion exchanger). Films were applied to a total thickness of 80-100 μ, and diffusion of hydrochloric acid followed. It is shown that the ion exchangers reduce the diffusion markedly, in admixture more than singly, and that the surface of each film presents a barrier to diffusion giving rise to intercoat blistering; this is explained on the basis of a higher degree of cross-linking of the surface than the interior. Practical trials on steel confirm the value of the addenda in reducing underfilm corrosion.—RPI. 19641

5.4.5, 2.3.5, 4.6.11

Evaluation of Protective Capacity of Painted Film Immersed in Artificial Sea Water by Dissipation Factor Measurement. (In Japanese.) G. Okamoto, T. Morozumi and T. Yamashina. J. Chem. Soc. Japan, Ind. Chem. Sect., **61,** No. 3, 291-295 (1958) March.

The dissipation factor (tan δ) of 13 painted mild steel specimens was measured in the frequency range of 0.2-10 k.c./sec after 2 or 3 hrs. of dipping the specimen in artificial sea water. An intermittent observation of a.c. resistance (1 k.c./sec) of the same samples was also taken. Specimens could be classified in two groups: one group with rather high values of tan δ (1.0-0.5 at 0.2 k.c./sec and 0.1-0.15 at 10 k.c./sec) and the second group with comparatively small values of tan δ (0.1-0.2). The a.c. resistance of the first group tended to decrease soon after immersion in artificial sea water while the a.c. resistance of the second group kept a high value of $\sim 10^4\ \Omega$ for several days.

Protective value of paints can thus be predicted by measuring the value of tan δ of the painted specimen even at the early stage of immersion.—JSPS. 19379

5.4.5, 6.3.6, 7.2

Plastic-Coated Copper Water Pipes. G. Wiedemann. Metall, **12,** No. 11, 1001-1003 (1958).

An illustrated review of the nature, properties—particularly heat insulation and corrosion-resistance—and economics of polyvinyl chloride-coated copper pipes for cold- and hot-water installations.—MA 19590

5.4.10

Wrapping for Protection with Petrolatum-Based Tape. W. A. Brewis. Corrosion Technology, **7,** 9-11 (1960) Jan.

A grease type wrapping based on petroleum jelly carried on cotton, glass or nylon gives complete protection to exposed or buried pipelines even in fresh or salt water. The main limitation is a temperature of 90 C. This wrapping is protected by an overwrapping of plasticized bitumen. When cathodic protection is called for the grease tape should be used with polyvinyl chloride backing. 19765

5.4.5, 2.3.5

Protective Action of Varnish Coatings. V. A. Kargin, M. I. Karyakina and Z. Berestneva. Doklady Akad. Nauk, **120,** No. 5, 1065-1067 (1958). (In Russian.)

The effect of diffusion by aggressive substances through varnish coatings was studied electrochemically by the method of anodic or cathodic polarization with a large potential difference; the method permits the estimation of the protective characteristics of film coatings. Using platinum as the cathode and varnish-coated iron as the anode, the amount and rate of corrosion by a 0.01 N solution of soda were measured and compared with those at an unprotected iron anode. Corrosion is a conversion of the metal into various chemical substances: their formation at the metal film contact layer signifies the appearance of a new phase. While the diffusion characteristics are a basic factor determining the protective properties of varnish and lacquer coatings, adhesion of film to metal was found to play a vital role; the high adhesiveness of some coatings inhibits the formation of the new phase at the film/metal contact layer.—RPI. 19257

5.4.5

Practical Experience with Protective Coatings at Pretoria. N. P. Nicolle. Inst. Sew. Purif., **11,** 208-209 (1958).

Bituminous coatings proved unsatisfactory for severe conditions, linseed oil/red lead primers with enamel finishing coat, graphite-based special preparations and anticorrosive and underwater coatings, aluminum paint and cold galvanizing proved unsuccessful on poorly cleaned surfaces, but rubber and chlorinated rubber paints were remarkably reliable under these conditions. Alkyd enamels proved fair and phenolic enamels over a zinc chrome primer were satisfactory. On flame-cleaned metal, plastic polyvinyl chloride over a primer and an intermediate coat was sound after 2 years. On sand-blasted surfaces, the best results were obtained with linseed oil/red lead primers topped with an enamel finish; rubber and chlorinated rubber paints were also satisfactory and plastic polyvinyl chloride coatings over a primer and intermediate coat system were very good.—RPI. 19347

TECHNICAL REPORTS on GENERAL CORROSION PROBLEMS

T-3A Some Corrosion Inhibitors—A Reference List. A Report of T-3A on Corrosion Inhibitors. Publication 55-3. Per Copy $1.50.

T-3B Bibliographies of Corrosion Products. Section One—A Report by NACE Technical Unit Committee T-3B on Corrosion Products. Publication No. 57-5. Per Copy $3.25.

T-3B Bibliographies of Corrosion Products, Section Two—A Report of NACE Tech. Unit Committee T-3B on Corrosion Products. Pub. 57-21. Per Copy $1.50.

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5.4.5, 5.9.1

Evaluation of Degree of Rusting on Steel Panels as a Basis for the Formation of Rust-Protective Paints. S. Alfort. Deutsche Farben-Z., **13**, No. 5, 177-183 (1959).

An account is given of current Swedish work on steel pretreatment and the selection of suitable primers, where particular attention is paid to the standardization of all the factors which might affect paint performance. It is suggested that previous studies in this field have overlooked the importance of reproducibility of surface structure and film thickness of the primer and that this may account for the widely diverse views on the value of zinc chrome. Six primers were selected for study, six steel pretreatments and four degrees of initial rusting (i.e., before painting). The present contribution is concerned specifically with a description of the nature of pretreatment and the effectiveness with which it is executed.—RPI. 19611

5.4.2, 7.7, 6.3.6

High-Temperature Electrical Insulating Inorganic Coatings on Wire. Period Covered: Feb., 1958-Jan., 1959. Clifton G. Bergeron, Arthur L. Friedberg, David L. Wilcox, Paul F. Schwarzlose and Robert L. Hallse. Illinois Univ. U. S. Wright Air Development Center, Technical Rept. 58-12 (Pt. II), Jan., 1959, 54 pp. Available from Office of Technical Services, Washington, D. C.

Further work on processing of coatings, coating continuity, multiple coating, formulation of coatings, oxidation of copper coated articles, high temperature electrical properties of coatings, and flexibility of coated wire are described. The technique of flow coating continuously moving wire through a porcelain enamel proved to be a practicable and successful technique for coating. Multiple coating secured insulation continuity. It was shown from studies on oxidation of coated copper specimens that copper oxide dissolved in the coating is not deleterious but rather beneficial to the high temperature electrical properties. (auth)—NSA. 19651

5.4.5

Metallic Lead as a Pigment for Anti-Corrosive Paints. J. A. Calcutt. Corrosion Prevention and Control, **6**, No. 11, 34-38 (1959) Nov.

Covers advantages of metallic lead pigments in paints, results of exposure tests in industrial atmospheres (specimens shown), typical paint formulations, and applications (cooling towers, gas tanks, dockside cranes, marine tanker and dredging plant). Because of low oxide content of pigment (99.5 Pb-0.5 PbO), metallic Pb paints can be made in reactive as well as non-reactive media. Primers have greater efficiency on imperfectly prepared surfaces, and have improved flow properties.—INCO. 19663

5.4.2, 6.3.6

Contribution to the Technology of (Copper) Wire Enamelling. Heinz Böttger. Draht, **10**, No. 6, 261-264 (1959).

The design of stoves and enamelling lines is described and the power consumption is estimated. In spite of the relative brittleness of the enamel it adheres well to the copper surface, owing to the formation of bonds between the polar molecule of the enamel and the pairs of free electrons of the copper atoms; but the wire must be thoroughly cleaned by passing the heated wire through steam containing methanol vapour. The properties of various enamels are considered, particular attention being paid to those which allow the copper wire to be tinned and soldered.—MA. 19662

5.4.5, 5.8.2

Use of Corrosion-Inhibiting Substances in Polyvinyl Acetate Metal Primers. J. C. Baatz. Paper Presented at the Sept. 1958 Meeting of the Am. Chem. Soc., Division of Paint, Plastics and Printing Ink Chem., Chicago, Illinois. Paint and Varnish Production, **49**, No. 7, 33-38 (1959).

A discussion of work on corrosion prevention by a dry paint film. The work was performed with a series of four corrosion-inhibiting pigments all containing a chromate portion, and five corrosion-inhibiting additives. A definite improvement in protection was obtained by using an emulsion-based binder with a chromate pigment or with an inhibiting additive, or with both together. Of the additives and pigments investigated, the most significant improvement was obtained with sodium nitrite and zinc yellow respectively. A combination of these two, together with a surface tension depressant to facilitate wetting of the metal surface, provided maximum corrosion prevention in the series of tests under discussion.—ZDA. 19684

5.4.5, 6.2.4, 6.2.3, 3.7.2, 2.2.2

Extra Durability of Paint on Low-Alloy Steels. H. R. Copson and C. P. Larrabee. Am. Soc. Testing Materials Bull., No. 242, 68-74 (1959) Dec.

Published information on comparative performance of paint coatings on low-alloy steels and mild steel is reviewed. Some current tests on painted steel specimens are described. Specimens of 3 types of steels, a C steel, a Cu steel, (Cr-Si-Ni-Cu-Mn), were exposed in spring of 1948 in an industrial atmosphere at Kearny, N. J., a semirural atmosphere at South Bend,Pan., and a marine atmosphere at Kure Beach, N. C. (800 ft. from ocean). Exposure results are tabulated. Two case histories (with photos) illustrate actual performance of paint coatings on large structures—railroad hopper cars, and a railroad bridge. Beneficial effect of alloying on atmospheric corrosion resistance of bare unpainted steel is briefly reviewed. Both field tests and service experience show that paint coatings are more durable on high-strength low-alloy steels than on carbon steel or on copper steel. Any rust which forms at breaks or holidays or underneath paint film is less voluminous on low-alloy steels. Owing to smaller volume of rust there is less rupturing of paint film and, hence, less moisture reaches steel to promote further corrosion. Extra durability of paint is due to improved corrosion behavior associated with alloy content of steels, with Cu, Ni, Cr, and P contents being particularly important. Graphs, tables, numerous photos of specimens, 10 references.—INCO. 19697

5.4.5

Applications of Epoxy Resin-Based Coatings in Corrosive Environments. H. Brull. Corrosion Technology, **6**, No. 10, 303-306, 312 (1959) Oct.

Brief and partial survey of properties and successful fields of application of epoxy resin-based protective surface coatings, with specific reference to Epikote resin. Storage-tank applications, process industries, pipeline coatings, nuclear energy uses, aircraft coatings, concrete coatings and others are reviewed.—INCO. 19724

5.8 Inhibitors and Passivators

5.8.1, 1.6

Inhibitors of Metal Corrosion. (In Russian.) Iya Nikolayevna Putilova, Stepah Afanas'yevich Balezin and Valeriy Pavlovich Barannik. Book, 1958, 183 pp. Goskhimizdat, Moscow, USSR.

A manual for engineering and technical personnel engaged in the chemical metallurgical and petroleum industries where the problem of metal corrosion arises is presented. The corrosion inhibitors for metals used in water, aqueous acid solutions, alkaline and salt solutions are described. The corrosion inhibitors for metals used in ordinary atmospheric conditions and in nonaqueous liquid media are also discussed. The theoretical concepts of the mechanism of corrosion inhibition are reviewed.—NSA. 19385

5.8.4, 5.9.2

List of Rust Inhibitors. (In Japanese.) Ichiro Shinozaki. Metals (Supplement), **28**, 7-14 (1958) October.

Surface cleaners and soluble rust preventive additives; petroleum derivatives; alkaline cleaning solutions; emulsions; electrolytic cleaning solutions; rust removers, soluble rust inhibitors. Preservatives; petrolatum oil; vaporizing inhibitors; sealers; anti-rust wrapping.—MR. 19450

5.8.4, 4.4.7, 3.5.9

Development of High Temperature Oxidation-Corrosion Inhibitors to Improve Stability of High Temperature Hydraulic Fluids and Lubricants. Quarterly Progress Rept. No. 4 (for) March, April, May and June 1958. Robert Brunier. Illinois Inst. Tech. August 29, 1958, 23 pp. ARF Project C-103. Available from Illinois Inst. of Tech., Armour Research Foundation, Chicago, Illinois.

The objective of this research program is to synthesize and evaluate selected organic compounds as high temperature oxidation-corrosion inhibitors in mineral oils, synthetic ester lubricants and silicone and silane fluids. As a result of this study specific inhibitors will be recommended for use. Some compounds were prepared which, according to previous test results, should have potential activity as inhibitors. The following compounds were prepared: N-(2-pyridyl)-1-naphthylamine, N,N'-Di-(2-pyridyl)-1,5-diaminonaphthalene, 10,10'-spirobiphenoxasilin, thiobutylstearamide, N-benzylthiobenzamide, N, N'diphenyl-2,5-pyrazine dicarboxylic acid dithionamide, and dimorpholinoyl-2,5-pyrazine dicarboxylic acid dithionamide. The testing program was devoted to the screening of new compounds. A large number of them containing the thionamide function which had previously been active. The compounds were tested for 24 hrs. at 550 F in the presence of 5 percent oxygen-95 percent nitrogen. The most efficient ones were also tested under more stringent conditions, 48 hrs. at 500 F in the presence of dry air. (auth)—NSA. 19761

5.8.3, 5.8.4, 4.3.2, 6.2.2

The Ohmic Resistance of Inhibitor Films with the Acid Corrosion of Iron. (In German.) W. Machu and H. I.

Morcos. Cairo Univ. Werkstoffe u. Korrosion, **11,** No. 2 (Supplement), 81-87 (1960) Feb.

The ohmic resistances of organic inhibitors in hydrochloric acid and sulfuric acid have been determined by means of direct resistance measurements. Depending on the concentration and on the type of inhibitor, the resistances were found to vary between 1 and 1200 ohm. The iron surface itself also has an influence. With poor inhibitors, their adsorption and desorption are slower. This process also depends on the concentration and type of inhibitor as well as on the surface condition of the iron. Where the inhibiting effect is good, the inhibitors are adsorbed by virtually the whole metal surface, that is to say, at local cathodes and anodes. A high film resistance corresponds to a high inhibiting effect, and vice versa. Apart from the adsorption rate, the quality of the inhibitor also depends on its solubility. 19303

5.8.4, 8.4.2

Use of Corrosion Inhibitors in the Gas Industry. Case of Pipeline Production. (In French.) C. Geoffray and A. Giampaoli. Paper before Gas Congr. Aix-les-Bains June 23-27, 1959. Rev. inst. franc. pétrole et Ann. combustibles liquides, **15,** No. 1, 186-216 (1960) Jan.

Film-forming and volatile inhibitors were evaluated for use in the internal protection of gas pipelines. A 10 percent spindle oil solution of a commercial amine-type inhibitor (IN) appeared best for lines not yet in service. Lanolin or boiled linseed oil was also effective, but a lanolin solution and a second amine-type inhibitor (K), widely used in the petroleum industry, were not. Immersion of steel coupons in water saturated with purified coal gas under pressure and containing various polar amine inhibitors showed that this type of inhibitor is completely satisfactory for town gas lines. In similar tests with oxygen-free Lacq gas containing traces of hydrogen sulfide, corrosion and embrittlement were controlled by diethylamine and by 10 percent spindle oil solutions of inhibitor IN or inhibitor K. 19743

5.9 Surface Treatment

5.9.4, 6.4.2

Investigation of the Mechanical Properties of Hard-Oxidized Aluminum Sheets. (In German.) P. Csokán and G. Sinay. Werkstoffe u. Korrosion, **11,** No. 4 (Suppl.), 224-227 (1960) April.

At the Metal Research Institute, Budapest, a new anodic method has been developed by means of which it is possible to obtain, within an hour, a 150-250 μ thick wear-resistant oxide layer which can easily be ground and polished and has a heat resistance up to 350-400 C. Light-metal components thus treated can find an extensive field of applications in telecommunications, electrotechnics, precision mechanics as well as in the textile, printing and vehicle industries.

The thickness of the oxide layer depends on the period of oxidation. The hardness measured with Hanemann's micro-hardness tester under a load of 100 g. amounts to 320-510 kg/mm^2 with pure Al, and to 360-520 HV kg/mm^2 with purest Al.

Comparative tests have been carried out with 0.8, 1.0 and 1.2 mm thick anodically treated and un-treated hard and soft pure Al sheets, in respect to tensile strength, yield limit, uniformity of elongation and bending strength. The results show that, depending on sheet thickness, duration of treatment and sheet hardness, the tensile strength, yield limit and uniformity of elongation are reduced, while the bending strength is increased. 19717

5.9.4

Anodized Aluminium Extrusions. Fred G. Shuler. Precision Metal Moulding, **16,** No. 11, 43, 48 (1958).

The anodizing process is briefly indicated, carried out after the extrusion of hot-alkali cleaned metal, and recommendations for choice of alloy are made. Proprietary finishes are noted.—MA. 19462

5.9.4, 6.4.2

A Study of Stripping Anodized Coatings from an Aluminium Alloy. Walter

TECHNICAL REPORTS

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T-1C Status of Downhole Corrosion in the East Texas Field—A Report of NACE Tech. Unit Committee T-1C on Sweet Oil Well Corrosion. Pub 57-23. Per Copy $1.50.

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T-1C Experience With Sweet Oil Well Tubing Coated Internally With Plastic—A Status Report of Unit Committee T-1C on Sweet Oil Well Corrosion. Pub. 58-8, Per Copy $1.50.

TP-1D Sour Oil Well Corrosion. *Corrosion,* August, 1952, issue. $1.50 Per Copy.

TP-1G Field Experience With Cracking of High Strength Steel in Sour Gas and Oil Wells. (Included in Symposium on Sulfide Stress Corrosion.) (Pub. 52-3) NACE Members $3.50; Others $5.00 Per Copy.

T-1G Sulfide Corrosion Cracking of Oil Production Equipment. A Report of Technical Unit Committee T-1G on Sulfide Stress Corrosion Cracking. Pub. 54-5. $1.75 Per Copy.

T-1G Hydrogen Absorption, Embrittlement and Fracture of Steel. A Report on Sponsored Research on Hydrogen Sulfide Stress Corrosion Cracking carried on at Yale University, Supervised by NACE Technical Unit Committee T-1G on Sulfide Stress Corrosion Cracking by W. D. Robertson and Arnold E. Schuetz. Pub. 57-17. Per Copy $5.50.

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Beck, John Danovich and Sara J. Ketcham. J. Electrochem. Soc., **106,** No. 12, 1063-1065 (1959).

A comparison of film removal from an aluminum alloy with an $HF-HNO_3$ system and a $CrO_3-H_3PO_4$ system is presented. It is shown that the use of $HF-HNO_3$ need not lead to metal losses by over-etching, and that this system should only be used when the concentration and exposure time are carefully controlled.—MA. 19732

5.9.4, 4.6.11, 4.3.3

The Protective Mechanism of Chromate Finishes on Zinc and Cadmium. (In German.) J. Elze. Metall, **13,** No. 8, 740-742 (1959) Aug.

The protective mechanism of chromate films is shown to depend on the prevention of any anodic or cathodic reaction. Results for sea water (pH 7.5) and chloride-free weak alkaline corrosion media are given. 4 tables, 5 figures. —ZDA. 19774

6. MATERIALS OF CONSTRUCTION

6.2 Ferrous Metals and Alloys

6.2.5, 4.3.3, 2.3.9

Study on Corrosion of Austenitic Stainless Steel by Uranyl Salt Solution. (In Japanese.) Gunji Shinoda, Tadao Sano and Tadashi Kawasaki. J. Japan Inst. Metals (Nippon Kinzoku Gakkaishi), **22,** No. 11, 592-596 (1958) Nov.

Applying surface radioactivity measurement, an autoradiographic method, and a weight-loss method, the corrosion resistance of some austenitic Cr-Ni steels against uranyl salt solution has been investigated. It was concluded that the count number and the autoradiographic method are useful to study the initial stage of corrosion mechanism. An X-ray diffractometer study was also made on welded specimens to examine the carbide precipitation and the ferrite formation, and the Nb carbide precipitated in the matrix was easily detected by an X-ray diffractometer study. The relative abundance of Nb carbide is less in the welded portion than in the other portion of base metal, and in the welded specimens there is no ferrite phase. Niobium-stabilized steels always show good corrosion resistance against uranyl salt solution. Some of the specimens were neutron-irradiated ($10^2 cm^2$/sec, 8 Mev) at about room temperature, and the irradiated specimens showed no change in the structure and the corrosion characteristics. (auth)—NSA. 19453

6.2.5, 3.2.2, 3.7.3

Corrosion Resistance of Stainless Steels. Intergranular Corrosion. (Continued.) (In Italian.) L'Acciaio Inossidabile, **25,** 61-72 (1958) May-June.

Heat treatment, fabrication and service conditions under which carbide precipitation occurs in austenitic stainless; methods of combatting susceptibility to intergranular corrosion.—RML. 19608

6.2.5

A New Steel for Honeycomb Structures. A. C. Gilbraith. Western Machinery & Steel Work, **49,** No. 11, 82-84 (1958) Nov.

Armco's PH 15-7 Mo has been developed to meet demands for a heat-treatable chromium-nickel steel. Produced especially for honeycomb fabrication it now permits parts made from the material to be hardened by heat treatment. In addition to this prime advantage, Armco PH 15-7 molybdenum has a high modulus of elasticity, excellent fatigue and high tensile properties. Its corrosion resistance in Conditions TH 1050 and RH 950 is superior to stainless steels of the 400 series. In Condition CH 900 its corrosion resistance is comparable to Type 302. Photos. —INCO. 19742

6.2.5, 8.2.2

The Use of Austenitic Steels in the New Power Station at Hüls. A. Engl. Mitt. Ver. Grosskesselbesitzer, No. 55, 255-264 (1958) Aug.

Tables list austenitic steels (grade according to DIN) employed in section of boiler operating at 300 atm. gauge pressure, in 140 atm. gauge pressure section of intermediate superheater I, in 300 atm. gauge pressure topping turbine and in 110 atm. gauge pressure condensing turbine. Quantities of austenitic material (wt. in metric tons) installed in different sections of plant are given, and chemical compositions of steels are tabulated. All of steels installed at Hüls contain 16 chromium, and a minimum of 13 nickel. They belong to group of austenitic steels where compared to 18-8 group, chromium content has been slightly reduced and nickel content raised in order to reduce their susceptibility to sigma formation in continuous service at high working temperatures. Factors governing selection of a steel for a particular application, high temperature strength, fabrication procedures, acceptance tests, welding practice, and occurrence of stress corrosion cracking are discussed. Graphs, photos, photomicrographs.—INCO. 19769

6.2.2, 6.2.3, 3.5.9, 3.7.2

Oxidation of Steel and Cast Iron at High Temperatures. (In Russian.) E. M. Blank. Metalloved. i Termicheskaya Obrabotka Metallov, **1959,** 53-54, Dec.

Effect of silicon and chromium content on oxidation resistance of steel at 900 C. Effect of silicon on oxidation resistance of gray cast iron with laminar graphite, and of S. G.-iron.—RML. 19671

6.2.5, 3.7.2

The Corrosion Resistance of Some Stainless Steels Alloyed with Cobalt. D. Coutsouradis. Cobalt, No. 5, 3-14 (1959) Dec.

Effect of Co on chemical properties is being studied in a series of Cr steels to which increasing amounts of Co were added. First results obtained on corrosion resistance of 17 and 27 Cr steel submitted to various heat treatments are presented in this paper. Total immersion tests (continuous and interrupted immersion) were performed to evaluate corrosion resistance of these steels in sulfuric acid at room temperature, and their susceptibility to intergranular corrosion was determined by employing Huey (boiling nitric acid) and Strauss tests. In some cases polarization curves were also determined, both by potentiostatic and intensiostatic methods. Co considered as an alloying element in Cr stainless steels exhibits a favorable influence on their resistance to overall corrosion and to intergranular corrosion after appropriate heat treatments. Experimental results are presented in numerous tables and graphs. Compositions of steels investigated (Co-containing and Co-free; some also containing Ni) are tabulated. 18 references.—INCO. 19691

6.2.5, 2.3.5, 3.6.8, 3.7.2

Corrosion and Metallographic Study of Stainless Steels Using Potentiostat Techniques. V. Cihal and M. Prazak. J. Iron and Steel Inst., **193,** Pt. 4, 360-367 (1959) Dec.

Availability of potentiostat techniques especially for electrochemical study of stainless steels is indicated. Characteristics of potentiostat and significance of potential polarization curves depending on chemical composition of alloy and etching characteristics of phases are described. Effect of Cr content on corrosion current in regions of activity and transpassivity was studied in Fe-Cr alloys. Polarization curves for Fe alloys containing 20, 36 and 42 Ni show that addition of Ni decreases maximum corrosion current in active region. Influence of some alloying elements (e.g. Mo, Cu, Ti, Si, Nb) on corrosion properties of 18-8 steels was investigated. Metallographic applications of potentiostat techniques include differential electrolytic etching at controlled potential, etching of stainless steels (18-8), etching in active and passive regions, etching in regions of transpassivity and secondary passivity, and transformation of delta ferrite in 18-9 Ti steel. Potentials for selective etching of phases (delta ferrite, sigma, austenite) in 18-8 steels are tabulated. Graphs, photo- and electron-micrographs, 39 references.—INCO. 19713

6.2.5, 3.7.4

Abnormal Grain Growth in Austenitic Alloys. B. Cina. J. Iron & Steel Inst., **194,** Pt. 1, 18-28 (1960) Jan.

Formation of abnormally large grains was studied in 3 fully austenitic alloys on solution of softening treatment at elevated temperatures. Alloys were NMC (4.00 Cr-8.35 Ni), FV 337 (17.52 Cr-17.68 Ni-6.83 Co), and FV 467 (13.8 Cr-9.55 Ni). It was found that such abnormal grain growth is related to prior hot-working history of material and can be induced by critical deformation at controlled temperatures. Mechanism for abnormal grain growth is one of secondary recrystallization for which experimental evidence is adduced. Process is complicated by presence of fine undissolved carbide particles at grain-growth temperature. These particles inhibit grain growth. Simple methods were found to minimize grain growth. In both FV alloys this consists of subjecting fine-grained recrystallized material to a small uniform amount of deformation at a particular temperature just before final solution or softening treatment. For NMC alloy, a deformation iln excess of critical had to be applied. Tables, graphs, photomicrographs, 19 references.—INCO. 19709

6.2.5, 3.2.2, 3.7.4, 2.3.6

The Problem of the Distribution of Precipitates in Corrosion-Resistant Austenitic Steels. V. Cihal and J. Jezek. Hutnicke Listy, **14,** No. 8, 695-700 (1959).

Study was made by means of electron microscopy. Preparation of a simplified extraction replica is described. For study of distribution of carbides in 18 Cr-9 Ni steels, a steel with 0.05 C-1.5 Mn-0.62 Si-18.48 Cr-9.34 Ni was chosen. Relationship between carbide precipitation and sensitivity of steel to intergranular corrosion and effect on notch impact strength was investigated. Precipitation of carbides of Cr and Ti 0.003 N was studied by method of preparing extraction prints. Crystalline formation of chromium carbide $Cr_{23}C_6$ is described. Table giving results of intergranular corrosion experiments, electron-micrographs, 21 references.—INCO. 19719

6.2.5, 2.3.5, 3.2.2

Intercrystalline Corrosion of Austenitic Stainless Steels. (In French.) L. Clerbois, F. Clerbois and J. Massart. Electrochimica Acta, **1,** No. 1, 70-82 (1959) April.

Potentiostat studies in an acid medium revealed a generalized corrosion, an intercrystalline corrosion and an oxidizing action. This method is more accurate than the empirical Strauss and Huey tests which involve errors, as was shown by an electrochemical investigation. 1 plate.—BTR. 19760

6.3 Non-Ferrous Metals and Alloys—Heavy

6.3.6, 3.2.2, 3.5.8

Corrosion Cracking of Brass in Ammonia. (In Russian.) A. N. Kondrat'ev. Metalloved. i Obrabotka Metallov (Metal Science and Treatment), **1958,** No. 12, 45-52. English Translation of Journal available from: Henry Brutcher, Technical Translations, P. O. Box 157, Altadena, Calif.

The potential (ϕ) of cast and annealed brass (zinc 30 percent) in 15 percent NH_4OH solution vs. the N-calomel electrode shifted in the more positive direction with increasing time, owing to the formation of a film of corrosion products. Values of ϕ for unstressed specimens were more negative than those for stressed specimens, and stress acted only as a mechanical factor. In an atmosphere of ammonia, reducing the moisture and oxygen contents of the gas to 14 and 90 mg/1, respectively, had little effect on the time to failure by stress-corrosion. However, further reductions led to a marked improvement and tensile tests showed that intercrystalline attack had not occurred. In corrosion tests in ammonium hydroxide solution containing various amounts of copper the copper content of the solution increased only up to 0.87-0.90 percent, but the zinc content continued to increase. An electrochemical mechanism leading to corrosion cracking is suggested; it includes two stages, and stress acts only as a localizer of corrosion.—MA. 19269

6.3.6, 3.5.8

Stress Corrosion Failure Checked in New Aluminum Bronze Alloy. Materials in Design Eng., **48,** No. 2, 123-124 (1958) Aug.

A new aluminum bronze alloy is available which is said not only to completely overcome stress corrosion failure, but to maintain a high degree of strength and corrosion resistance up to 500 F. New copper alloy, Ampco Grade 8, contains 6.5 aluminum, 2.3 iron, 0.25 tin and 0.25 percent of silver, nickel and manganese. It is addition of 0.25 tin to analysis that prevents stress corrosion cracking. As a result, it is no longer necessary to stress relieve finished fabrications. Also, alterations, repairs or field changes can now be made without stress relieving. Graphs, tables. —INCO. 19299

6.3.3, 6.3.18, 3.7.2

Vanadium-Chromium Alloy System. O. N. Carlson and A. L. Eustice. Ames Lab. U. S. Atomic Energy Commission Pubn., IS-47, November, 1959, 18 pp. Available from Office of Technical Services, Washington, D. C.

On the basis of data obtained from melting point determinations, microscopic examination, and X-ray investigations, a phase diagram is proposed for the V-Cr alloy system. The system forms a complete series of solid solutions with a minimum occurring in the solidus at 1750 C and approximately 70 wt. percent chromium. No intermediate phases were found in this system. Hardness and corrosion data are presented as a function of alloying composition. (auth)—NSA. 19720

6.3.6. 3.7.2

Influence of Small Quantities of Nickel on the Oxidation of Copper. (In French.) F. Bouillon and J. Stevens. Acta Metallurgica, **7,** 774-776 (1959) Dec.

Oxidation was carried out in pure oxygen at atmospheric pressure at temperatures equal to or below 200 C. Under these conditions, there always exists a large region where only Cu_2O is formed. This study shows that: 1) the alloys of Cu-Ni containing 5 and 10 percent nickel oxidize less rapidly than pure copper during the period studied; 2) alloys containing 0.5 and 1 percent nickel oxidize more rapidly during an initial period, the length of which varies inversely with the nickel content; 3) the alloys containing 0.1 percent oxidize the most rapidly during the period investigated; 4) the oxide CuO always appears sooner on these alloys.—BTR. 19652

6.3.5, 6.3.13, 3.2.3

Unstable Suboxides and Hydrides of Niobium and Tantalum. (In German.) G. Brauer and H. Müller. Plansee Proc. 1958, **1959,** *257-262*; disc., *262-263*.

The oxidation of finely divided niobium and tantalum powders in air at 300 C yielded new suboxides in addition to the pentoxides. The suboxide of niobium is thought to be Nb_2O, and can be synthesized from niobium and Nb_2O_5. Tantalum has two suboxides, viz. Ta_2O and another of undetermined composition. The suboxides decompose above 350 C in the absence of further oxidation to the pentoxide and metal. Niobium powder and HF form NbH_2, with a fluorite structure.—MA. 19648

6.3.6, 3.5.9

Aluminium Bronze. G. FitzGerald-Lee. Automobile Engr., **49,** No. 10, 376-380 (1959) Oct.

Retention of high proportion of strength at elevated temperatures and resistance to oxidation and corrosion make Al bronzes best Cu-based alloys for many applications in steam plant, internal combustion engines and chemical engineering applications involving moderately elevated temperatures (up to at least 400 C). Characteristic equilibrium diagram for Cu-Al alloys is shown. Progressive change in mechanical properties of 10 percent Al bronzes, with and without Fe, due to decomposition of β into $(\alpha + \gamma 2)$, during 4-week period, is tabulated. Other tabulated data include results of tensile tests at room temperature and at 400 C; mechanical properties at various temperatures including subnormal temperatures; creep test results; results of notched-bar impact tests at elevated temperatures; and resistance to oxidation and scaling at 400 C in air, with and without additions of moisture, SO_2 and HCl gas. Test specimens were Al bronzes of various compositions some containing nickel. Information courtesy of Copper Development Association. Tabulated data were compiled by various investigators.—INCO. 19773

6.3.6, 3.2.3

Study of Dry Oxidation on Copper-Nickel Alloys. (In French.) F. Bouillon and J. Stevens. Industrie Chimique Belge, **24,** 1335-1341 (1959) Nov.

Data on thin films of oxide formed on Cu alloys containing 0.5 to 10 percent Ni at high oxygen pressures and temperatures from 150-200 C; morphology and composition of films formed at high temperatures (500-900 C) and low pressures. Speed of reaction and nature of oxide products is influenced by Ni content of specimens. 19 references.—RML. 19692

6.3.5, 3.7.2, 4.7, 4.6.2

Metallurgical Studies of Niobium-Uranium Alloys. John A. DeMastry, Frederic R. Shober and Ronald F. Dickerson. Battelle Memorial Inst. U. S. Atomic Energy Commission Pubn., BMI-1400, December 7, 1959, 44 pp. Available from Office of Technical Services, Washington, D. C.

In a continuing program, fabrication characteristics, physical and mechanical properties, and corrosion behavior in air, CO_2, NaK, water, and steam were studied for binary niobium fuel alloys containing 10, 20, 30, 40, 50 and 60 wt. percent uranium. To evaluate the effects of two major impurities of niobium, oxygen and zirconium, three niobium base stocks, differing according to the level of these impurities, were used for each alloy. The impurity combinations employed were 600 ppm oxygen and 0.74 wt. percent zirconium, 700 ppm oxygen, and 0.17 wt. percent zirconium, and 300 ppm oxygen and 0.02 wt. percent zirconium. Representative specimens of these alloys retained their hardness up to 900 C. The 10 and 20 wt. percent uranium alloys were successfully forged at 2500 F and rolled at 1800 F to sheet. Fabrication characteristics of the remaining alloys are under investigation. The 0.2 percent offset yield strength of the 10 wt. percent uranium alloy was 57,200 psi at room temperature and 36,900 psi at 1600 F. For the 20 wt. percent uranium alloy it was 93,200 psi at room temperature and 71,000 psi at 1600 F. The corrosion life of all of the alloys in air at 572 F and in CO_2 at 600 F was superior to that of unalloyed niobium. In 1000-hr. exposures to 600 F water most of the alloys exhibited corrosion rates only two or three times greater than that of Zircaloy-2. All of the alloys appear compatible with NaK at 1600 F. The impurity combinations employed in the base niobium appeared to have no effect on the corrosion behavior and mechanical properties of the alloys. (auth)—NSA. 19712

6.3.5, 3.8.4

Reactions in the Niobium-Hydrogen System. William M. Albrecht, W. Douglas Goode, Jr. and Manley W. Mallett. Battelle Memorial Inst. U. S. Atomic Energy Commission Pubn., BMI-1332, April 1, 1959, 21 pp. Available from Office of Technical Services, Washington, D. C. See also: J. Electro-

.chem. Soc., **106,** No. 11, 981-986 (1959).

Equilibria in the niobium-hydrogen system were determined in the range 100 to 900 C, 0.1 to 1000 mm of mercury hydrogen pressure, and hydrogen/niobium atomic ratios of 0.01 to 0.85. X-ray measurements were obtained at 25 to 400 C at hydrogen/niobium ratios up to 0.54. The studies showed that a solid solution of hydrogen in niobium is produced throughout most of the system. A miscibility gap was found at low temperatures and pressures, with a critical point at about a temperature of 140 C, a hydrogen pressure of 0.01 mm of mercury, and a hydrogen/niobium ratio of 0.3. Sorption rates at 300 to 550 C were initially linear. At higher temperatures, sorption rates were controlled by diffusion in the metal matrix. Diffusion coefficients at 600 to 700 C can be expressed by $D = 0.0215 \exp [(-9370 \pm 600)/RT]$. Desorption rates were lower than those predicted by diffusion. (auth)—NSA. 19617

6.3.15

Corrosion Resistance of Titanium. A. H. Barber. Corrosion Prevention and Control (Corrosion Engineer), **6,** ii-xiv (1959) Nov.

Current information on corrosion resistance of titanium is summarized in series of tables (resistance to single chemicals and simple mixtures, in plant environments, to liquid metals). Certain aspects are discussed in detail, including general properties, resistance to sea water and brine, stress corrosion, galvanic corrosion, oxidizing agents and acid media, continuous anodic passivation of titanium, miscellaneous applications, and economic considerations. Review is given of platinized titanium electrodes, their characteristics and uses. —INCO. 19654

6.3.15, 5.2.2, 5.3.2

Titanium-Platinum Anodes. (In Italian.) G. Bombara and D. Gherardi. Metallurgia Italiana, **51,** 462-465 (1959) Oct.

Anodic behavior in sea water of titanium in a titanium-platinum couple and of titanium with a welded or galvanized coating of platinum. Introduction of platinum in any form greatly increases efficiency of titanium anodes in corrosion prevention.—RML. 19726

6.3.4, 3.5.9

History, Status, and Future of Cobalt Alloys. Gleen A. Fritzlen. (Amer. Inst. Min. Met. Eng. Conf. on) High-Temperature Materials, 1957, **1959,** 56-80.

The development of cobalt alloys to meet the demands for materials with greater hardness, resistance to impact, wear, and corrosion, high-temperature strength, and longer life is traced from 1899. Structures are described, and the role played by the different constituents in promoting the unique properties of cobalt alloys is discussed. It is predicted that cobalt alloys will be developed for operation up to 2000 F (1095 C).—MA. 19740

6.3.10, 3.7.2, 7.8

Properties of Vacuum-Melted Nickel-Aluminium and Nickel-Titanium Alloy Wires. (In Japanese.) Toshio Doi. J. Japan Inst. Metals (Nippon Kinzoku Gakkai-Si), **23,** No. 3, 181-184 (1959).

Changes in UTS, elongation, and grain-size produced by annealing, elevated-temperature UTS, and resistance to corrosion and oxidation were measured on wires prepared by forging and drawing from vacuum-melted ingots of Ni alloys containing aluminum up to 6 or Ti 7.5 per cent. The UTS of Ni-Al 6 per cent and Ni-Ti 7.5 per cent alloys was higher than that of special steels at moderate temperature, and higher than that of W or Mo at elevated temperatures. Ti was more effective than Al in increasing the strength of Ni because of the greater difference in atomic radii. Oxidation- and corrosion-resistance increased with Al content, but Ni-Al 4.5 per cent alloy showed particularly low values. Corrosion-resistance decreased slightly and oxidation-resistance increased slightly with Ti content.—MA. 19759

6.3.5, 3.5.9, 3.7.2

Oxidation of Niobium-Chromium Alloys at Elevated Temperatures. Charles A. Barrett and Francis J. Clauss. (Electrochem. Soc. Symposium on) Technology of Niobium 1958, **1958,** 98-105. John Wiley & Sons, Inc., New York.

Niobium-chromium alloys containing chromium 0.8-11.6 percent were prepared by powder-compacting and sintering at 3500 F (1925 C). Specimens were exposed at 800, 1000 and 1200 C for 2½ hr. and weighed in situ at frequent intervals. Subsequent examination was by X-ray diffraction, chemical analysis and metallography. At 800 C maximum corrosion-resistance is obtained with ~8 at. percent chromium; at 1000 C oxidation-resistance increases continuously with increasing chromium content (max. 11.6 percent); at 1200 C the presence of chromium within the range stated had no effect on oxidation-resistance. 12 references.—MA. 19627

6.3.10, 6.3.4

Nickel- and Cobalt-Base Alloys. F. S. Badger and G. A. Fritzlen. (Am. Soc. Metals Conf. on) Metals for Supersonic Aircraft and Missiles, **1958,** 234-257; disc., 257-260; Appendix 363-364.

Some of the available engineering data necessary for aerodynamic applications of Ni- and Co-base alloys are discussed. Ten wrought alloys readily available in sheet form are described and their characteristics compared with A.I.S.I. Type 304 and 316 stainless steel. The physical and chemical properties of these alloys which make them useful for service above 1000 F (540 C) are described. Thermal expansion, thermal conductivity, thermal shock, oxidation-resistance, carburization, radiation effects, specific heat, d, emissivity and melting ranges are included. Mechanical properties, including room-temperature tensile data, elevated-temperature strengths, modulus of elasticity, stress-rupture and creep strengths, endurance and impact properties, formability and fabricability are also discussed. Thermal effects on properties are summarized. An appendix is given on the effect of irradiation on hardness and tensile properties. 24 references.—MA. 19637

6.3.21, 8.4.5

The Corrosion of Thorium and Its Alloys. W. E. Berry, R. S. Peoples and H. A. Pray. (Am. Soc. Metals Conf. on) The Metal Thorium, 1956, **1958,** 267-276.

The behavior of thorium and its alloys in contact with environments encountered in the several types of power reactors is discussed. The corrosion problems presented when ThO_2 is used as a reactor fuel are considered.—MA. 19678

6.3.20, 3.5.4, 8.4.5

Failure of the Normal Zircaloy Fuel Rod No. 1 and Pre-Irradiation Testing of The Replacement Fuel Rods. Interim Report. R. F. Boyle. Westinghouse Electric Corp. Atomic Power Div. U. S. Atomic Energy Commission Pubn., WAPD-PWR-PMM-3391, 1959, 13 pp. Available from Office of Technical Services, Washington, D. C.

The X-I-N irradiation experiment is designed to test the hydriding mechanism of the fuel rod failure and to establish the relative merit of N-free-Fe replaced Zircaloy as compared to normal Zircaloy with respect to hydrogen adsorption behavior. The experiment consisted of two PWR-type fuel rods with a 0.005-in. drilled defect hole located approximately over the center of the first UO_2 pellet. Failure of the defected normal Zircaloy rod in the test occurred by the opening, through a water-logging action, of a crack already present in the tubing prior to irradiation. —NSA. 19661

6.3.19, 3.2.2, 3.5.9

Etch Pits in Zinc. G. Bassi and J. P. Hugo. J. Inst. Metals, **87,** 376-379 (1959) July.

Experiments were performed on coarse grained zinc containing 0.002 percent tin. Annealing between 100-400 C was found to lead to the development of etch pits which were smaller and more numerous at the lower temperatures, increasing in size and decreasing in number with rise of temperature. This behavior is explained by diffusion of tin atoms in the zinc. 16 illustrations.—ZDA. 19665

6.3.16, 3.7.4, 7.7

Relation Between the Microstructure of Tungsten and Its Behavior as a Low-Voltage Contact Material. (In French.) R. Bernard. Plansee Proc. 1958, **1959,** 55-67; disc., 67-68. Metallwerk Plansee AG., Reutte/Tyrol, Austria.

The performance of tungsten contacts cannot be predicted either by chemical analysis or hardness determination. On the other hand, metallographic examination reveals marked differences in the microstructure assumed to be in direct relation to the metal performance. A very fine, long-fiber structure appears preferable for good contact performance. Generally, a coarse, short fiber, recrystallized structure leads to poor performance favoring surface oxidation and metal transfer between the electrodes. Sintered tungsten contacts have the advantage of a very small metal transfer, and the surface oxidation is also smaller, but wear is greater, probably on account of a tearing out of the grains.—MA. 19669

6.3.6, 3.7.2

Effect of Titanium Addition in Alpha-Brass. S. K. Biswas and S. C. Das Gupta. Trans. Indian Inst. Metals, **12,** 175-184 (1959) June.

The effect of adding 0.08-1.22 percent titanium was studied. The limit of solid solubility lies between 0.68 and 1.22 percent titanium. Corrosion-resistance in sea-water, 10 percent H_2SO_4, and 15 percent NaOH is improved by titanium as long as no second phase is formed. Titanium improves oxidation-resistance up to approximately 350 C; hardness and UTS are also improved and grain growth is inhibited.—MA. 19675

6.3.19, 8.8.5

Aluminium-Base Zinc-Base Alloys for Permanent-Mould Castings. E. Belkin. Foundry, **87,** No. 8, 70-74, (1959).

Alloys of composition Zn 50-65, Al 50-35 and Cu 1-5 percent, are considered to be of considerable potential value for permanent-mould casting. Mechanical properties, resistance to intergranular corrosion, creep strength, dimensional stability and casting properties are tabulated in detail and reviewed. 11 references.—MA. 19686

6.3.20, 3.7.3, 8.4.5

The Corrosion Behavior of 3.5 w/o Natural Uranium-Zirconium Base Fuel Alloy. E. G. Brush, R. E. Campagnoni and M. A. Powers. Knolls Atomic Power Lab. U. S. Atomic Energy Commission Pubn., KAPL-M-REC-1, June 16, 1959, 42 pp. Available from Office of Technical Services, Washington, D. C.

Tests were conducted to determine the corrosion behavior of 3.5 wt. percent (natural) uranium-zirconium base fuel alloy as a function of heat treatment and test water medium. Ten heat treatments and three water media were involved. A comparison of method of surface treatment was also evaluated. The results indicate that there were no significant differences in the corrosion behavior of the alloy among the three water treatments. They also indicate that the effect of surface treatment upon weight change was insignificant, except in the case of one heat treatment. The heat treatments may be classified in order of decreasing corrosion resistance as follows: 1) rapidly quenched; 2) slowly cooled from 800 C; 3) furnace cooled from 950 C; and 4) air cooled from 950 C. From the 950 C heat treating temperature (above the transformation range), it appears that furnace cooling produces a more corrosion resistant alloy than air cooling, while from 800 C (below the transformation range) no difference in corrosion rates is evident between furnace and air cooling. Analytical expressions for the corrosion behavior of each heat treatment are presented. (auth)—NSA. 19723

6.3.20, 4.6.1, 5.12, 8.4.5

Hot Water Corrosion Resistance of Hanford Zirconium and Zircaloy-2 Tubing. M. D. Carver and E. T. Hayes. Bureau of Mines. U. S. Atomic Energy Commission Pubn., USBM-U-53, Oct. 5, 1955 (Changed from Official Use Only August 28, 1959), 14 pp. Available from Office of Technical Services, Washington, D. C.

Samples of two types of Hanford reactor tubing, zirconium and Zircaloy-2, in each of four conditions, as rolled, stress relieved in air at 800 F, stress relieved in argon at 800 F, and vacuum annealed at 1400 F, were subjected to hot water corrosion tests to determine the relative effect on the corrosion resistance of each of the three heat treatments following fabrication. Also, it was undertaken to determine what effect an etching treatment following fabrication would have on the corrosion resistance. It was found that for both types of tubing a longer life in hot water was obtained from vacuum annealing at 1400 F than from any of the other conditions in which the specimens were tested. Of the other three conditions, none was shown to be definitely superior to the other two. The results show that, for both types of tubing, etching can be expected to improve the corrosion resistance of the as-rolled tubing and of the as-rolled tubing which has been subjected to a stress relief in argon. The results show also that, for both types, etching can be expected to lower the corrosion resistance of the as-rolled tubing which has been subjected to a stress relief in air. Furthermore the results show that, for the as-rolled tubing which was subjected to vacuum annealing at 1400 F, etching either did not affect or affected only slightly the corrosion resistance of Zircaloy 2 tubing, but improved the corrosion resistance of the zirconium tubing. (auth)—NSA. 19711

6.3.20, 3.7.4, 4.6.1

Effect of Carbon and Its Distribution on the Corrosion Resistance of Zirconium in Water at 315 C. (In French.) H. Coriou, J. Gauduchau, L. Grall and J. Hure. Mém. Sci. Rev. Mét., **56,** 693-703 (1959) Dec.

Zirconium carbide is more reactive in water than zirconium. Corrosison process correlated with network of distribution of carbide. Process of deformation of the specimen; characteristics of oxide films.—RML. 19710

6.4 Non-Ferrous Metals and Alloys—Light

6.4.2, 2.3.7, 2.2.2, 2.3.2

Exposure Tests of Aluminum Alloys SG100A and G8A. Progress Report of Subcommittee V on Exposure and Corrosion Tests. Appendix to Report of Committee B-6 on Die-Cast Metals and Alloys. Proc. Am. Soc. Testing Materials, **58,** 167-172 (1958).

Summarizes results of indoor aging tests, of atmospheric exposure tests at New York (industrial) and Sandy Hook, New Jersey (marine); and of accelerated corrosion test in 20 percent NaCl spray for bars of G8A (8 Mg-Al alloy) and SG100A (9.5 Si-0.5 Mg-Al alloy). Tables and graphs show effects of ageing and corrosion on mechanical properties (tensile strength, yield strength, elongation and Charpy impact).—INCO. 19389

6.4.2, 4.3.2, 5.8.2

Inhibition of Corrosion of Aluminum in Acid Solutions. J. Sundararajan and T. L. Rama Char. J. Sci. Ind. Research (India), **18B,** 387-388 (1958). Chem. Absts., **53,** No. 8, 6972 (1959) April 25.

The inhibition of corrosion of aluminum by HCl (0.5N to 4.0N) by acridine, thiourea, nicotinic acid, dextrin and tannic acid was studied. Acridine is the preferred inhibitor, giving protection even at concentration of 0.02 g/1 in 1.0N HCl, and protects the metal at higher normalities.—ALL. 19523

6.4.2, 3.7.2

Effects of Iron and Silicon on the Blackening of Aluminum. Yoshino Yamasaki, Hachiro Onbe, Shoji Nakamura and Hiromitu Harimoto. J. Metal Finishing Society of Japan, **9,** 422-426 (1958) Nov. (In Japanese.)

Low-silicon aluminum alloy shows slightly lighter color than with low-iron aluminum alloy, but in higher silicon alloy the differences in the degree of blackening are little.—MR. 19606

6.4.4, 3.8.4, 2.3.9

Oxidation of Magnesium Single Crystals and Evaporated Films. Richard R. Addiss, Jr. Cornell Univ., Ithaca, New York. Technical Rept. No. 1 on Contract Nonr-401 (31). May, 1958, 95 pp. Order PB 138822 from Library of Congress, Photoduplication Service, Publications Board Project, Washington 25, D. C.

Apparatus and techniques were developed for measuring the oxidation of magnesium single crystals at high temperatures, and evaporated magnesium films at room temperature, with a sensitive microbalance capable of operating in an ultra-high vacuum. Single crystals were oxidized at an oxygen pressure of 2.5 mm mercury and temperatures of 400 and 440 C.—GRR. 19615

6.4.2, 3.2.2, 3.5.8, 3.4.8

The Influence of Cations on Intercrystalline Corrosion in Aluminum Alloys. (In German.) Friedrich-Carl Althof and Harald Spindler. Z. Metallkunde, **50,** 574-581 (1959) Oct.

Cationic influence on stress corrosion and intercrystalline corrosion of Al-Mg-7 and Al-Cu-Mg alloys. Interrelation between intercrystalline and stress corrosion in salt solutions; dependence of the corrosion formation on the pH values, dipping time and solution concentration. 16 references.—RML. 19614

6.4.2, 4.3.5, 3.5.9, 3.8.4

The Oxidation of Aluminium in Dry Oxygen in the Temperature Range 400-650 C. D. W. Aylmore, S. J. Gregg and W. B. Jepson. J. Inst. Metals, **88,** No. 5, 205-208 (1959-60).

The kinetics of the oxidation of high-purity aluminum sheet in dry oxygen at 7.6 cm mercury pressure was studied at a series of fixed temperature ranging at 50° intervals from 400 to 650 C. The oxidation runs were continued for periods of at least 170 hr. and at 450 C for 400 hr. The oxidation at 400 C, apart from the first 2 hrs., followed a parabolic-rate law, while the curves of weight gain against time for the higher temperature consisted of three distinct branches over which the rate respectively decreased, was constant and decreased again to a very small value, $\sim 0.05\ \gamma/cm^2/hr$. The weight grains after 170 hr. oxidation were smaller the higher the emperature, apart from the 400 and 650 C runs. The results are interpreted in terms of a crystallization of an initially formed amorphous oxide layer; this model is consistent with the electron-diffraction investigations of other workers. (auth)—MA. 19643

6.4.2, 3.6.5, 3.6.6

Corrosion of Aluminium Alloys. G. FitzGerald-Lee. Automobile Engineer, **49,** No. 6, 215-217 (1959) June.

This article first discusses the qualitative aspects of electrolytic corrosion. The table gives the solution potentials, with respect to a calomel electrode, of thirty well-known metals and alloys. With regard to the electrolytic corrosion of iron coupled with aluminum, the author considers that aluminum spraying the iron gives the best protection, zinc spraying or galvanizing being the next best alternative (here the zinc is subsequently slowly eroded). Zinc spraying ironwork is felt to be preferable to painting with zinc-rich paints. Where zinc or zinc die casting alloys are in contact with aluminum, the author does not consider that any special precautions against corrosion are called for; there is usually only a slight attack on the zinc. Zinc alloy die castings that have been nickel/chromium plated (B.S. 1224) are considered safe in contact with aluminum in 'moderate' atmospheres. 1 table.—ZDA. 19741

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Corrosion

OFFICIAL MONTHLY PUBLICATION

National Association of Corrosion Engineers

An Association of Individuals and Organizations Concerned with Control of Corrosion

1061 M & M Building Houston 2, Texas

Vol. 16 October, 1960 No. 10

Topic of the Month

Corrosion by Urban Cooling Waters*

By SIDNEY SUSSMAN¹

Introduction

WATER TREATMENT specialists and industrial cooling system operators have long been aware of problems generated by the dissolved solids increase and aeration which occur in circulating cooling waters. If an operator avoids the pitfalls of reduced heat exchange capacity resulting from scale formation, he is likely to fall into the grip of corrosion because of the absence of protective films on metal surfaces.

Refrigeration and air conditioning installations have been increasing at a rapid rate in non-industrial urban buildings. A lack of awareness of water-caused problems, inadequately trained and insufficient maintenance personnel, poor equipment location, and air pollution frequently combine to produce spectacular corrosion failures in urban installations. For example, copper condenser tubes in one system perforated in only ten days. Corrosion failures within an air conditioning season are not too unusual.

Such rapid failures are not widespread geographically because most public water supplies have sufficiently high alkalinity to buffer the acid picked up from moderately contaminated air. However, wherever low alkalinity water combines with relatively high sulfur dioxide in the air, the frequency of corrosion failures and degree of acidity in untreated recirculating cooling waters become impressive.

Most water supplies in New England, the Middle Atlantic coastal region, the southern Appalachian highlands, and the Pacific Northwest have low alkalinities. The more highly populated urban areas provide higher average sulfur dioxide concentrations. The extent and intensity of these conditions may be seen from Table 1 which shows partial analyses of makeup waters and some untreated circulating cooling waters from a number of Eastern cities. Note how absorption of sulfur oxides reduced circulating water alkalinity enough to form free acid in most cases and increased the sulfate-chloride ratio.

Abstract

Untreated recirculating cooling waters are likely to become corrosive when low alkalinity waters are present in an area where there is a relatively high sulfur dioxide air content. Untreated circulating cooling waters are compared with makeup waters for eight Eastern cities for such factors as pH, alkalinity, chloride content, sulfate/chloride ratio, and corrosion products. New York City water is discussed specifically. Corrosion can be mitigated by alkaline pH adjustment with maintenance of satisfactory chromate concentrations.

4.6.4

New York City Water

Probably no other city combines low alkalinity water and highly polluted air to the same degree as New York. The water used for makeup in hundreds of cooling systems contains only 10 ppm alkalinity as $CaCO_3$. The Department of Air Pollution Control has reported an average sulfur dioxide content of about 0.1 ppm in the air during the summer with 0.5-0.6 ppm peaks.[1] In winter the situation is worse with average sulfur

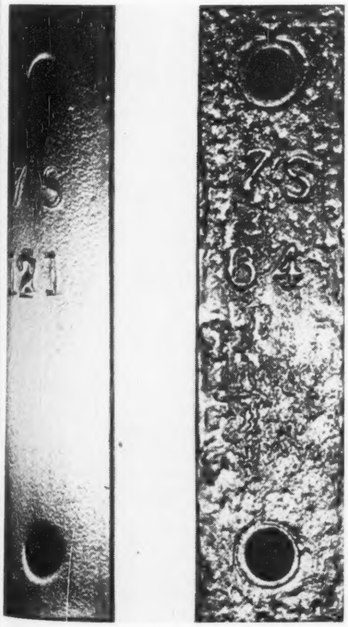

Figure 1—Left: New test coupon; right: Coupon after 42-day exposure in untreated cooling tower in New York City.

TABLE 1—Comparison of Untreated Circulating Cooling Waters with Makeup Waters

City	Water*	pH	Alk.	Acid	Cl	Ratio SO_4/Cl	Corrosion Products Fe	Cu	Zn
Springfield, Mass.	M C	6.8 4.4	8 2	0 0	2 15	3.5 4	0 0.5	0 25	0 0
New York, N.Y.	M C	6.9 2.8	10 0	0 28	3 81	3 11.9	0 84	0 3	0 380
Newark, N. J,	M C	7.2 4.0	13 0	0 7	5 4	3.4 30.	0 43	0 3	0 . . .
Philadelphia, Pa.	M C	7.0 3.9	28 0	0 5	16 355	2.4 6.4	0 39	0 180	0 . . .
Lancaster, Pa.	M C	7.5 4.3	136 0	0 2	16 931	2.9 3.8	0 250	0 0.5	0 0.5
Wilmington, Del.	M C	7.3 3.7	43 0	0 10	14 120	1.9 7.5	0 30	0 15	0 . . .
Baltimore, Md.	M C	8.0 3.2	46 0	0 120	8 116	1.7 9.1	0 28	0 1.4	0 3
Richmond, Va.	M C	8.3 4.1	26 0	0 1	15 610	2.5 3.0	0 53	0 3	0 Trace

* M = Makeup (City Water).
C = Circulating Cooling Water (Untreated).
Note: Corrosion Products, Alk, Acid and Cl are in PPM.

★Submitted for publication June 3, 1960.

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dioxide concentrations rising to 0.25 ppm and 0.8 ppm peaks.

The widespread effects of this air and water combination was shown by pH measurements on untreated circulating water samples collected from 1,544 evaporative cooling units in New York. pH values as low as 2.5 were observed. Fifty (3.2 percent) had a pH below 4, 150 (9.7 percent) were circulating free acid (pH below 4.4), and 1,193 (77.3 percent) had a pH below 7.0.

Frequent rapid corrosion failures testify to the aggressiveness of such waters. Corrosion rates of 400 MDD and more are observed with mild steel exposed 6-8 weeks in New York cooling towers. Figure 1 shows a cleaned test coupon after such exposure (right), with an unexposed control at left. Corrosion of mild steel coupons in 52 untreated evaporative cooling units averaged 58 MDD. This represents serious corrosion of the thin steel employed in smaller equipment.

Fortunately, reliable corrosion control procedures are available. Most effective of these is alkaline pH adjustment with maintenance of satisfactory chromate concentrations. Corrosion of mild steel in 55 chromate-treated units in New York averaged only 3.1 MDD, with none higher than 9 MDD.

As indicated elsewhere,[2] treatment of urban units is not without its special problems—many having no relationship to the chemistry of corrosion control treatment.

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1. L. Greenburg and M. B. Jacobs. *Industrial and Engineering Chemistry*, **48**, 1518 (1956).
2. S. Sussman. *Corrosion*, **13**, 701t-710t (1957) Nov.

Any discussion of this article not published above will appear in June, 1961 issue.

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Film Formation Versus Film Maintenance in Cooling Water Inhibitor Performance★

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Abstract

Corrosion inhibitors in open recirculating cooling water systems require rapid and complete film formation for maximum effectiveness. The protective film is established on clean surfaces by initial treatment with inhibitor at high dosage levels. Protection then can be maintained by continuous treatment at substantially lower levels. If operational difficulties should cause loss of the protective film, low level treatment after the film has been lost may result in severely increased corrosion and deposition.

Laboratory corrosion, deposition and consumption studies with polyphosphate-based and chromate-based inhibitors illustrate the advantages of high level start-up and low level maintenance treatments. These data are confirmed by actual field experiences. 5.8.1

Introduction

OPEN RECIRCULATING cooling water systems depend for successful operation upon the use of effective water-treatment chemicals to control corrosion, microbiological growths and deposition on heat transfer surfaces. The cost of using these chemicals versus the cost of repairs and downtime resulting from treatment failures, is an important factor in the economics of many industrial operations. Problems involved in the selection and application of water-treatment chemicals are therefore a major concern both to chemical suppliers and to operators of industrial cooling towers.

This paper is concerned with one part of this field: the proper method of applying inhibitors in recirculating cooling water systems to obtain effective control of corrosion and deposition at minimum dosages and costs. High corrosion rates and severe deposition on heat transfer surfaces often have resulted from the use of corrosion inhibitors at low dosage levels during start-ups or immediately following periods of low pH operation. It is shown that a combination of high dosage level start-up treatment to establish a protective film, followed by maintenance of this film at commonly employed low concentrations (or maintenance levels) of inhibitor with good pH control is the best way to obtain low corrosion rates and good heat transfer at reasonable treatment costs.

In this paper, the term corrosion is defined as the reaction of a metal with its environment resulting in loss of metal either generally over the surface or from localized areas. Corrosion products are the solid reaction products of the corrosion reaction. Fouling and deposition are used as synonyms referring to the laying-down of solid deposits on a metal surface. These deposits generally consist of three types: corrosion products, suspended matter carried in the water, and scaling products. Scaling refers specifically to the deposition of minerals from the water (such as calcium carbonate and calcium phosphate).

It should be understood that although corrosion and fouling are independent phenomena, they often occur together. That is, high corrosion rates often (but not necessarily) result in severe desposition on the metal surface.

Although several different types of inorganic compounds are used for corrosion control in recirculating cooling water, the present work was confined to chromate-based and polyphosphate-based treatments. Corrosion and fouling data were obtained with coupons and electrical resistance measuring probes in laboratory equipment simulating typical cooling tower operations. Field experience has corroborated this labortory data.

Experimental Section

The test method employed for this work was essentially the same as that used by Bregman and Newman.[1] The equipment is shown in Figures 1 and 2. The test involves measurements of corrosion and deposition of metal coupons and electrical resistance measuring probes in a system incorporating the major variables associated with open recirculating cooling water systems. Briefly, coupons and probes were suspended in a vessel containing a synthetic cooling water plus inhibitor. The treated water was added to this vessel and allowed to overflow to the drain every 18 minutes. This rate corresponds to a 1.3 fold replacement of the water daily. The vessel was thermostated at 140 F, a common metal tube wall temperature on heat transfer surfaces in industrial cooling systems. Related studies in this laboratory have shown that the data obtained in this apparatus correlate very well with similar data obtained in heat transfer equipment.

The electrical resistance measuring probes were used to follow fluctuating corrosion rates accurately. Coupons provide only average rates of corrosion over the entire period of exposure, whereas the electrical resistance measuring device makes possible detection of slight variations in corrosion rate during the test. With the electrical resistance measuring device, rates of formation of protective films can be measured, and loss of protection caused by changing conditions can be observed almost immediately.[2, 3] Laboratory strip probes, Models 1003 (mild steel) and 1001 (Admiralty), designation S4X1, were manufactured by the Crest Instrument Company. Probe preparation consisted only of a 30-second immersion period in inhibited hydrochloric acid to activate the surface. Even with this activation treatment, a few probes still behaved in a passive manner for a short period; however, this initial passivity was overcome, and long term corrosion rates correlated well with those obtained with initially active probes (see Figure 3).

The test coupons were either 20 gauge SAE 1010 mild steel or 20 gauge arsenical inhibited Admiralty, 1 inch x 2 inches in area, prepared as described by Bregman and Newman.[1] The coupons were used primarily to measure deposition and to supply an active metal surface (20 square inches per test) to the test water. Five coupons were used in each test. The coupons were removed and processed at the end of each test to obtain total deposition and to provide a check on average corrosion rates obtained with the electrical resistance measuring device. It was found that corrosion rates obtained by both methods generally correlated well, as shown in Table 1. Similar results have been reported by other authors.[3]

The detailed test procedure has been described previously.[1] In the present work, the pH of the test vessel was controlled between 6.0 and 6.5 for polyphosphate-based treatments, and between 6.5 and 7.0 for chromate-based treatments. In all cases, when polyphosphate-based treatments were used, the concentrations were calculated in terms of the total phosphate present. Similarly, concentrations of chromate-based treatments were calculated in terms of total chromate. Probe readings were obtained frequently during each test, and water samples were taken intermittently for phosphate and chromate determinations. The test period

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★Submitted for publication February 17, 1960. A paper presented at the 16th Annual Conference, National Association of Corrosion Engineers, Dallas, Texas, March 14-18, 1960.

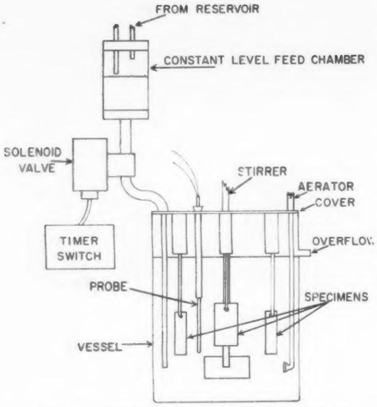

Figure 1—Drawing of corrosion test apparatus.

was generally 14 days, but some tests were carried out for longer periods. The test apparatus was arranged so that up to 16 tests could be performed simultaneously. Figure 2 shows seven test units in operation.

Discussion of Results

The fundamental mechanisms of corrosion protection with chromate or polyphosphate-based inhibitors in cooling waters still are not completely understood. Nevertheless, it is generally agreed that protection is obtained by reaction of the chromate or polyphosphate or both with the metal surface and with certain water constituents to form what is known as a protective film. The metal surface has a specific demand for inhibitor based on the area susceptible to corrosive attack. This active surface will either corrode in the absence of an inhibitor, or will react in the presence of an inhibitor to form a protective film on the metal surface.

When a polyphosphate or chromate-based inhibitor is applied initially in a clean system, the inhibitor concentration in the water is observed to decrease with time.[4] This effect, which is aptly described as consumption of inhibitor, results from the formation of protective films. The rate at which the film is formed is related to the inhibitor concentration in the water. Should the concentration of inhibitor fall below a certain minimum level, film formation may be sufficiently slow to allow corrosion to continue unchecked in non-filmed areas. Corrosion may be rapid enough to suppress film formation through the accumulation of corrosion products. These corrosion products may then further reduce the available corrosion inhibitor concentration by reacting with the inhibitor to form more deposits. Also, localized high pH levels near corroding areas on the metal surface will allow some inhibitor to react with calcium hardness in the water, forming scales. Deposits formed in this way are voluminous, porous, and nonprotective. Because circulation of water through the deposits is low, inhibitor will be consumed quickly beneath the deposits and corrosion rates may be increased through local concentration cell action.

Figure 4 illustrates the results of good and poor film formation. Test coupons, upper left and right, respectively, were treated with polyphosphate-based and chromate-based inhibitors at maintenance dosages of 20 and 15 ppm for four days. These coupons illustrate the characteristic fouling and corrosion which occurs when a good protective film cannot form. Because of the heavy deposits present, these coupons would be very difficult to protect from further attack, even with high inhibitor dosages.

When corrosion inhibitors are applied at a concentration high enough to satisfy the initial demand, film formation generally is rapid and complete. With good film formation during the early corrosion stages, total corrosion and deposition of corrosion products can be maintained at very low levels. The lower left and right coupons in Figure 4 were treated with 60 ppm of inhibitor for the first four days. The good protective films which formed were effectively maintained at much lower levels of inhibitor, 20 ppm of phosphate and 15 ppm of chromate, respectively. These coupons show much less corrosion and desposition compared to the upper two coupons, even though the lower coupons were exposed over a longer period of time.

Inhibitor Consumption on Steel Surfaces

Polyphosphate and chromate-based inhibitors are consumed at high rates during the initial corrosion protection process. Figure 5 illustrates consumption of polyphosphate-based inhibitors at various levels of treatment. The phosphate contents of these tests started at 60, 40, 30, and 20 ppm. After 24 hours the phosphate levels were 60, 29, 16, and 4 ppm, respectively. In the test at 40 ppm, the inhibitor level returned to its original value after six days, while the 30 ppm did not reach its original value in 14 days. The 20 ppm test was down to 4 ppm and still dropping when the test was stopped after two days.

Table 2 shows the relationship between deposition on the test panels and corrosion rates with various levels of polyphosphate-based treatment. The deposits found on the coupon surfaces are primarily corrosion products. These data show that inhibitor was consumed and deposits were formed at rates directly related to the corrosion rate and metal surface area. It can be seen that even though the corrosion rate at 20 ppm, for example, was higher than at 60 ppm, the deposition at 20 ppm was much larger than at 60 ppm. This corresponds to the greater consumption of phosphate at 20 ppm, as shown in Figure 5.

Initial consumption of inhibitor also occurs with chromate-based inhibitors. However, because of the anodic nature of chromate-based inhibitors, pitting attack is quite severe at low inhibitor levels. Increasing the inhibitor concentrations decreases the pitting tendency. Concentrations of chromate treatments vs. time are presented in Figure 6 and Table 3. It can be seen that the amounts of chromate-based inhibitors consumed were all in the range of 4 to 6 ppm after 24 hours regardless of concentration. However, corresponding corrosion rates, pitting, and deposition of corrosion products decreased with increasing inhibitor dosages.

Initial High Level Treatments on Steel Surfaces

The benefits of continuous high level treatment and the problems of corrosion, deposition, and inhibitor consumption which arise when insufficient inhibitor is present have been clearly shown. However, in most large industrial systems, blowdown, spray losses, cycles of concentration, make-up, etc., make it uneconomical to use inhibitors continuously at dosages as high as 60 ppm of total phosphate or total chromate.

Fortunately, as was shown in Figure 4, it is unnecessary to operate at these high levels, provided that rapid and complete film formation can be established during the first days of operation. Figure 7 shows corrosion rates on steel, obtained with polyphosphate-based inhibitors at various treatment levels. Test A demonstrates low level start-up at a dosage of 20 ppm. As can be seen, the corrosion rate starts high because the metal surface is active. The rate begins to drop as the corrosion-inhibiting film forms. However, a complete film cannot be formed because of the rapid consumption of polyphosphate at 20 ppm (see Figure 5). The polyphosphate concentration in the solution never reaches a level sufficient to form a complete protective film. Corrosion continues on the unprotected surface, and the corrosion products form a porous, unprotective deposit. Soon the entire surface is covered, and the corrosion rate climbs rapidly, resulting in heavy deposition and an unprotected surface. In Test B, the same inhibitor used in Test A was applied at 60 ppm for four days, and then reduced to 20 ppm. The differences in corrosion rates are apparent. The amount of deposition

TABLE 1—Correlation of Probe and Coupon Corrosion Rates

Treatment	Test Period (Days)	Average MPY Rate (Probes)	Average MPY Rate (Coupons)
Polyphosphate-based	14	3.1	3.5
Polyphosphate-based	57	1.0	1.3
Chromate-based	18	2.2	2.5
Chromate-based	14	3.0	2.0

TABLE 2—Corrosion Tests with Polyphosphate-based Inhibitors

Continuous Treatment (as ppm PO_4)	Average MPY Rates (14 days)	Total Deposition mg/sq. cm.
Blank	70 ± 10	40.7
60	1.0	1.4
40	1.5	4.2
20	49	33.7

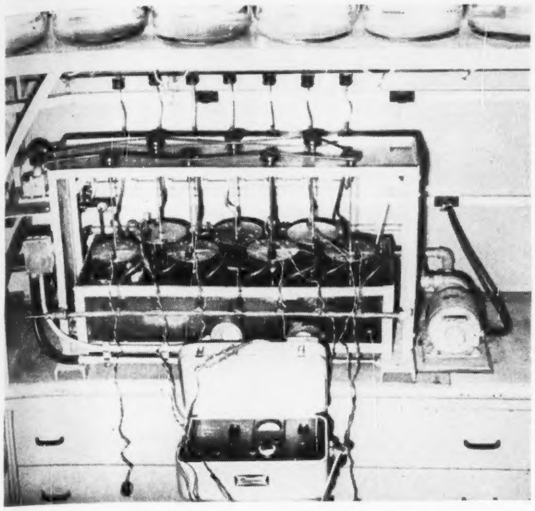

Figure 2—Photograph of corrosion test apparatus.

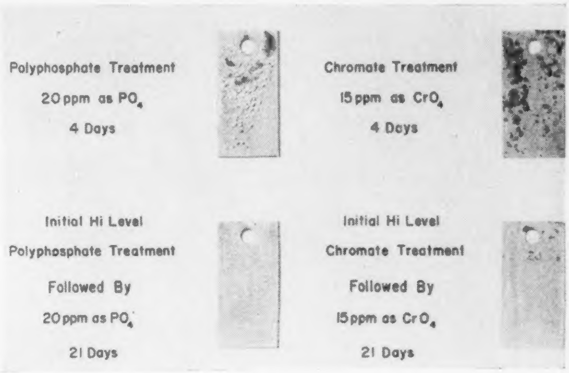

Figure 4—Comparison of inhibition and deposition by high level and low level treatments.

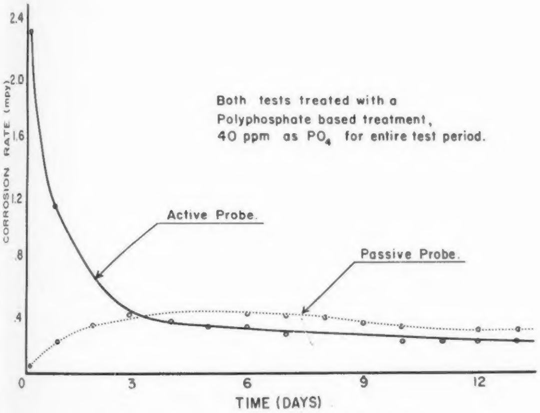

Figure 3—Comparison of active and passive probes.

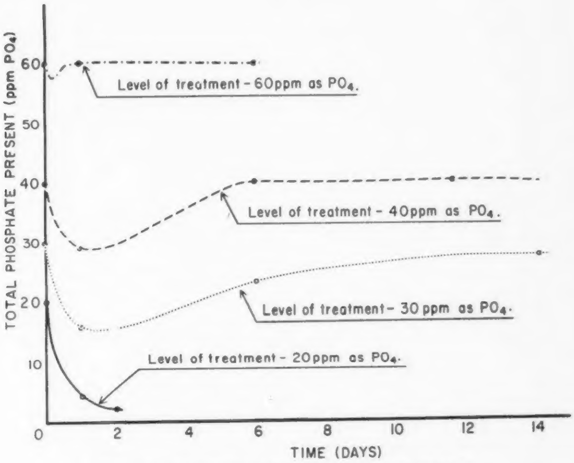

Figure 5—Consumption of phosphate on steel surfaces.

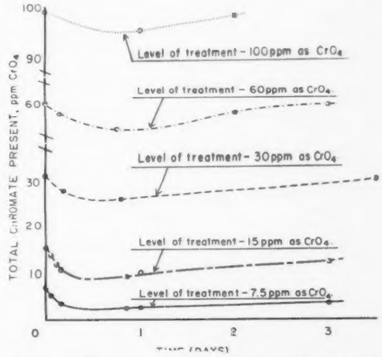

Figure 6—Chromate consumption on steel surfaces.

in this test was very low. Rapid and complete film formation was obtained through the use of initial high level start-up. The follow-up treatment at the maintenance dosage level effectively maintained the protective film. Test C illustrates a blank.

The requirement for rapid film formation is just as essential with chromate-based as with polyphosphate-based inhibitors. Maintenance level dosages of chromate-based inhibitors are not able to form a protective film rapidly enough to combat excessive corrosion and pitting. Figure 8 shows the effects of dosage level on corrosion rate with chromate-based inhibitors. In Test D, inhibitor was applied continuously at 15 ppm. Test E shows the same inhibitor applied at 60 ppm for 4 days, and then at 15 ppm for 10 days. In Test D the corrosion rate at the end of 14 days was still gradually decreasing. In Test E, however, the initial corrosion rate was lower than in Test D, and continued to decrease with time. Test C is a blank.

Table 4 presents quantitative corrosion and deposition data obtained with chromate-based and polyphosphate-based treatments. Clearly, corrosion and deposition are closely related. In both types of treatment, the amount of deposit which formed with 60 ppm initial high level treatment followed by 20 ppm maintenance treatment is close to that formed in tests run at continuous high level.

High Level Applications on Admiralty

Initial inhibitor consumption occurs to a much greater extent on steel surfaces than on other metals, particularly copper or the copper-based alloys. Also, inhibitor requirements for the protection of the copper alloys are lower than for steel. However, high level start-ups are beneficial in systems containing copper alloys as well as in all-steel systems. Figure 9 presents corrosion rate data for Admiralty, illustrating the benefits of initial high level treatment. Test F shows that with 15 ppm of a polyphosphate-based inhibitor, the corrosion rate was higher than in Test G, which incorporated initial high level treatment at 60 ppm of the same inhibitor, followed by a maintenance level of 10 ppm of the same inhibitor.

On both steel and copper alloyed surfaces, the use of inhibitors during start-up at normal low maintenance levels may eventually result in a reasonable level of corrosion control. However, under such conditions, deposits may build up rapidly. These deposits will consist largely of corrosion products intermixed with inhibitor. Although corrosion rates become low in time, a relatively large quantity of metal may be

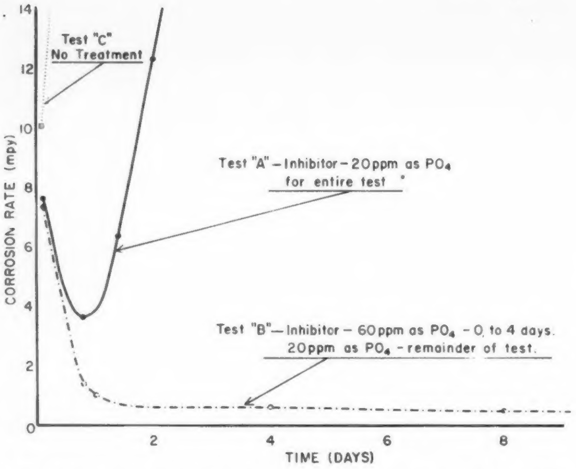

Figure 7—Comparison of initial high level and continuous low level polyphosphate based treatments on corrosion of steel.

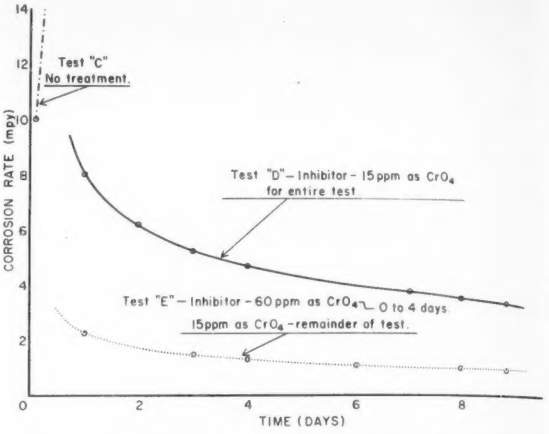

Figure 8—Comparison of initial high level and continuous low level chromate based treatments on corrosion of steel.

TABLE 3—Corrosion Tests with Chromate-based Inhibitors

Continuous Treatment (as ppm CrO_4)	Average MPY Rate (14 days)	Total Deposition mg/sq. cm.
Blank	70 ± 10	40.7
100	2.0	......
60	2.6	1.6
30	2.8	4.2
15	4-5	6.8
7.5	8-12	11.6

TABLE 4—Corrosion Rates and Deposition—High Level and Continuous Treatments

Type	Concentration of Inhibitor as ppm PO_4 or CrO_4	Average MPY Rates (14 days)	Total Deposition mg/sq. cm.
Polyphosphate-Based	60 ppm— 4 days 20 ppm—10 days	0.6	2.0
	60 ppm—continuously	1.0	1.4
	20 ppm—continuously	49	33.7
Chromate-Based	60 ppm— 4 days 15 ppm—10 days	0.9	1.5
	60 ppm—continuously	2.6	1.6
	15 ppm—continuously	4-5	6.8

lost during the early stages of inhibitor application. The deposits in such systems usually are porous, thus making the surface more receptive to further deposit build-up if conditions should change slightly.

Fluctuating Conditions

It has been established that with chromate and polyphosphate-based inhibitors, high level treatment followed by continuous low maintenance dosages will effectively control corrosion and deposition in recirculating cooling water systems. Should the inhibitor level drop below the required film maintenance dosage, or if other circumstances, such as poor pH control, should cause the film to be removed, high level treatment may be required to re-establish protection.

Figure 10 shows changes in corrosion rates under fluctuating conditions. Total corrosion is represented by the solid line and the left hand ordinate, while daily changes in corrosion rate are shown by the dotted line and the right hand ordinate. In this test, a protective film was established by treatment with a polyphosphate-based inhibitor at 60 ppm for the first four days. At point A, the level was reduced to 20 ppm to maintain this film. The protective film provided low corrosion rates and low deposition. Treatment was stopped at point B, and soon thereafter the corrosion rate began to rise. At C, two days later, the inhibitor was returned to the 20 ppm maintenance level. Since only slight film removal had occurred, corrosion control was quickly re-established. During periods B and C, an increase in deposition was observed. From point C to D, protection became essentially the same as from point A to B except for the increased deposit.

At D, treatment was again terminated for 3 days. The corrosion rate began to rise, and at E, treatment was again supplied at the normal maintenance level of 20 ppm. This time, however, maintenance-level treatment did not reestablish protection, because too much of the protective film had been lost. High level treatment was required at point F to produce a stable, low corrosion rate. At G, the 20 ppm level again became effective for maintenance. At H, treatment was again stopped. The system was acid cleaned at I because during the entire period beyond point D, severe deposition had occurred. The most critical time was after point E, when the low maintenance-level treatment was reapplied in an attempt to re-establish the film. Acid cleaning at I removed the deposits and reactivated a clean metal surface. High level treatment for four days at J formed a protective film which was maintained at K with the original maintenance dosage. These conditions essentially controlled corrosion and deposition as in the beginning of the test run.

Field Application

The laboratory tests reported above were conducted at the minimum inhibitor levels required to establish and maintain films in the laboratory test apparatus. Actual field applications may employ inhibitors at slightly higher levels.

A typical case history of film formation and maintenance in an actual plant is shown in Figure 11. During 40 days of normal operation, the inhibitor level was held at 20 to 30 ppm, with a pH of 5.8 to 6.2. The average corrosion rate was 5 mpy. Erratic controls that followed caused loss of the protective film, and the corrosion rate increased drastically. Protection was re-established quickly by high level inhibitor application at 60 ppm for three days. Steady dosage at the 20 ppm maintenance level coupled with good pH control continued the excellent corrosion protection for another 40 days. During the period of erratic controls, some deposition occurred and remained after the high level treatment, but further deposition was prevented. Protection was lost again at a later period, and was re-established by high level treatment for three days after the proper pH level had been obtained.

Figures 10 and 11 also illustrate a procedure for obtaining rapid formation of the protective film through the application of high level treatment. The electrical resistance measuring probe can be used as an effective method of determin-

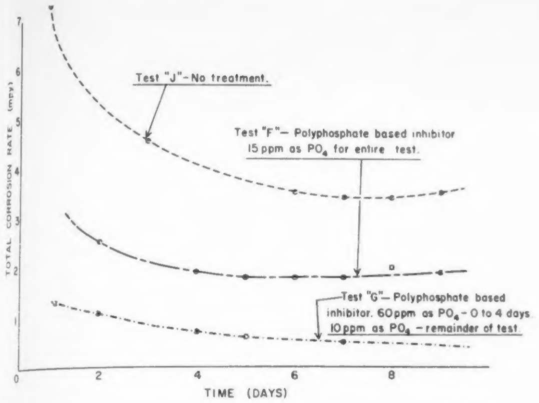

Figure 9—Comparison of initial high level and continuous low level polyphosphate based treatments on the corrosion of Admiralty.

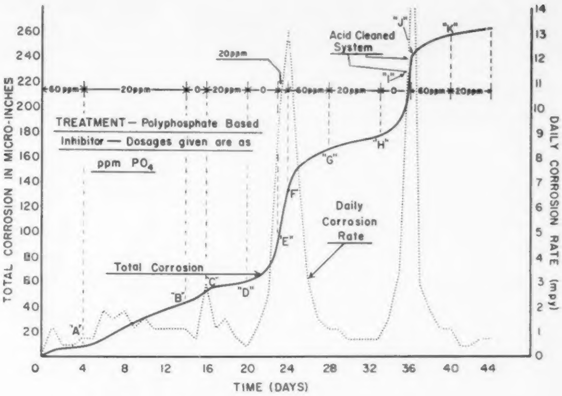

Figure 10—Effect of changing inhibitor dosage on film maintenance.

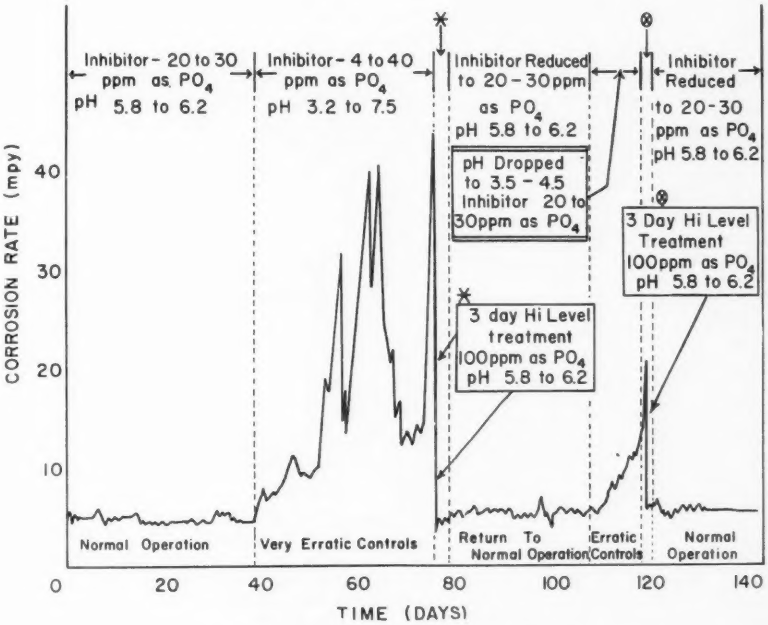

Figure 11—Plant data illustrating high level treatment.

ing the proper time for high level application and as a means of measuring the extent of film formation.

A typical procedure for establishing the protective film is as follows:

1. The system should be cleaned to remove old corrosion deposits and scale by appropriate means, followed immediately by:

2. High level inhibitor treatment with proper controls to maintain the necessary residuals and pH values, while monitoring corrosion with electrical resistance measuring probes.

3. High level treatment should be continued until corrosion rates drop to a low level. Generally 3-5 days are required for this. However, under severely corrosive conditions, longer times may be needed.

4. When corrosion rates have diminished and remain constant, the inhibitor treatment can be switched to low levels to maintain the protective film.

Many plants have instituted a regular program of high level inhibitor dosages during turnarounds and whenever corrosion rates increase substantially. Constant monitoring with the electrical resistance measuring device provides warning of loss of protection and indicates the need for high level treatment to re-establish protection.

A review of the plant operating data in Figure 11 and the fluctuating conditions shown in Figure 10 illustrate the importance of maintaining proper control of inhibitor levels and pH values to reduce corrosion and deposition. If controls are not maintained effectively, severe corrosion, deposition and loss of protective film may occur. In many such cases, cleaning and reapplication of high level treatment may be required. The need for proper controls on the operation of the cooling system cannot be over emphasized. Many plants have incorporated pH controller-recorder equipment and increased testing frequency to assure better controls. The result generally has been greatly improved corrosion protection, reduced scaling, and less plant maintenance.

Conclusion

1. Laboratory and field testing with chromate and polyphosphate-based inhibitors has shown that in open recirculating cooling water systems, initial high level inhibitor application rapidly establishes a protective film that can be maintained with continuous low dosages. Low corrosion and deposition rates can be obtained with this type of inhibitor application. Initial and continuous application of low inhibitor dosages may result in acceptable corrosion rates, but may be accompanied by heavy deposition of corrosion products. Continuous high level inhibitor treatment is effective against both corrosion and fouling, but is generally economically unfeasible.

2. Should corrosion protection be partially or entirely lost because of lower than required maintenance levels, low or high pH conditions, or other abnormal situations, protection may be re-established with high inhibitor dosage for short periods with a minimum degree of deposition. Attempting to re-establish protection with maintenance dosages of inhibitor usually results in severe deposition and increased corrosion. The laboratory data have been substantiated by actual field applications.

3. The experimental data reported in this paper illustrate the value of electrical resistance measuring probes for determining and following corrosion rates in a cooling water system.

Acknowledgments

The authors are indebted to Dr. A. J. Freedman and Mr. E. H. Hurst for their advice and guidance in the preparation of this paper, and to Mr. D. B. Boies, Mrs. J. Crowther, and Miss B. Northan for their experimental assistance.

DISCUSSION

Questions by Giles A. Rawls, Port Arthur, Texas:

1. Did you check corrosion rates on coupons as well as on electrical resistance measuring probes? How did they compare?

2. Did you use same probe throughout test?

Replies by W. J. Ryzner:

1. Coupons were checked closely as shown in Table 1. These data show the relationship of corrosion rates from coupons and probes to be comparable. The comparison can only be made with the average corrosion rates.

2. Yes. A single probe was used during an entire test. This probe allowed fluctuating corrosion rates to be calculated during the run, simply by changing the microinches measurement to mpy rate of metal loss.

Question by Norris J. Landis, Standard Oil Company (Ohio), Cleveland, Ohio:

How do the high level initial and the continuous low level treatments compare with respect to suppressing pitting attack, for both polyphosphate and chromate treatments?

Reply by W. J. Ryzner:

Of the two types of inhibitors, Chromate treatments are much more prone to pitting attack than the polyphosphate treatments. The high level treatment substantially reduces the pitting tendency by forming the protective film rapidly and uniformly. Low level treatments without benefits of high level are susceptible to pitting attack due to imperfect film formation. Once a protective film is established, normal low level of inhibitor sufficient for film maintaining would prevent any corrosion from occurring. This includes pitting as well as localized or general type.

Question by A. S. Couper, Standard Oil Company (Indiana), Whiting Indiana:

If PO_4 and CrO_4 form protective films, do you find an acceleration of corrosion (over the blank) at very low inhibitor concentration? How low an inhibitor concentration have you tested?

Reply by W. J. Ryzner:

The phenomenon of accelerated corrosion at very low inhibitor concentrations over that occurring with a blank is more common among organic inhibitors in organic media. However, with cooling water treatments this effect is not as pronounced. Perhaps the increase in localized and pitting attack is confused with this tendency. In cooling water systems, the anodic inhibitors such as chromates, at low inhibitor levels cause an increase in pitting attack due to incomplete film formation. The attack is concentrated at the pit areas and gives the appearance of more severe attack over the type of corrosion occurring on the blank test. We have investigated inhibitors of all types at very low levels and find only aggravated pitting or localized attack which usually is equivalent or less than the corrosion of a blank test.

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Any discussion of this article not published above will appear in June, 1961 issue.

Estimating the Cost of Corrosion In Refinery Crude Units*

By N. J. LANDIS

About the Author

N. J. LANDIS has been a materials and corrosion specialist in The Standard Oil Company (Ohio) Manufacturing Department in Cleveland, Ohio, since June, 1955. He has a BS in chemical engineering from Case Institute of Technology (1954) and is a member of the NACE.

Abstract

The cost of corrosion was estimated for refinery crude oil distillation units in a detailed study. This program was conceived as the first step in determining the cost of refinery corrosion on a unit throughput basis. A knowledge of the overall cost of corrosion is regarded by management as a valuable aid in assigning manpower and facilities most effectively to corrosion work. Capital, maintenance and operating costs were all considered. A significant result of this cost study was that the actual cost of corrosion was far less than prior estimates by the industry would have predicted. Of equal importance are the methods evolved in gathering and analyzing the various types of cost data. In their general form these methods should be applicable in corrosion cost studies for all types of process units. 1.2.2

Introduction

THE PETROLEUM refining industry has long been concerned with the question of the cost of corrosion in refineries. The importance of obtaining answers to this question has increased steadily with increasing competition in the industry. It is true that production losses may comprise most of the cost of corrosion when corrosion causes forced shutdowns. However, this category of corrosion cost is not generally available, since it depends on a multitude of transitory and intangible factors. Rather, the corrosion engineer is concerned with the cost of countermeasures to reduce corrosion costs.

As defined in this sense, "corrosion" includes all forms and degrees found in the refinery, both active and potential. The urgency of need for a solution to a particular corrosion problem is here irrelevant; it is of major importance that countermeasures be properly directed so that the maximum benefit is given to the profitability of the refining operation. This economic approach, on a broad basis, is essential for determining which corrosion problems should be concentrated on and how much energy should be expended in controlling them.

Progress in developing broad-scale corrosion costs has been slow, because of the very magnitude of the work itself and because of the difficulty in obtaining accurate basic cost information. In 1954 the API Subcommittee on Corrosion published a preliminary estimate that corrosion was costing the refining industry between 11 and 19 cents per barrel of crude charge.[1] While it is not within the scope of this paper to discuss this result, more detailed work has been needed in order to establish a useful and reliable estimate. This paper is therefore offered as a contribution in this area, the emphasis being in particular on the development of techniques for determining basic costs. As defined here, basic costs include the material and labor costs associated with the purchase of new equipment, the maintenance of existing equipment and the operation of corrosion control facilities.

Early in this work it was felt that progress could best be made by limiting the study at first to a specific unit. In this way, such efforts as proved to be misdirected would not be expended in overly time-consuming projects, and the study could be kept within manageable proportions. As satisfactory approaches and techniques became known, the study could be enlarged to cover other refinery units.

The type of unit considered best for this study was a crude distillation unit, because crude units are basic refining components included in almost every refinery. Also, crude units experience a large share of the total corrosion in a refinery. The particular units selected were twin crude units which went on stream in 1952 at Sohio's Cleveland Refinery. Each unit consisted of a two stage, atmospheric-vacuum tower system, with its own stripping and naphtha fractionating facilities, but with a common light-ends recovery system (Figure 1).

Capital Cost of Corrosion Protection

One of the basic corrosion costs is the cost of the corrosion protection built into new equipment. This corrosion protection consists of alloy, alloy lining and added wall thicknesses where conventional materials are used. Costs in this category are termed the capital cost of corrosion. While the total capital cost of corrosion protection is itself a significant number, it is also important to know how this cost is broken down among different types of equipment. Such information is of value in locating areas of potential cost savings. The equipment size factor, as well as the corrosivity factor, is brought into perspective.

Methods Used in Estimating Capital Costs

From a survey of possible approaches, it was found that a variety of data and information sources would be needed for this study. It was also necessary to develop some specialized techniques for the acquisition and treatment of data. An

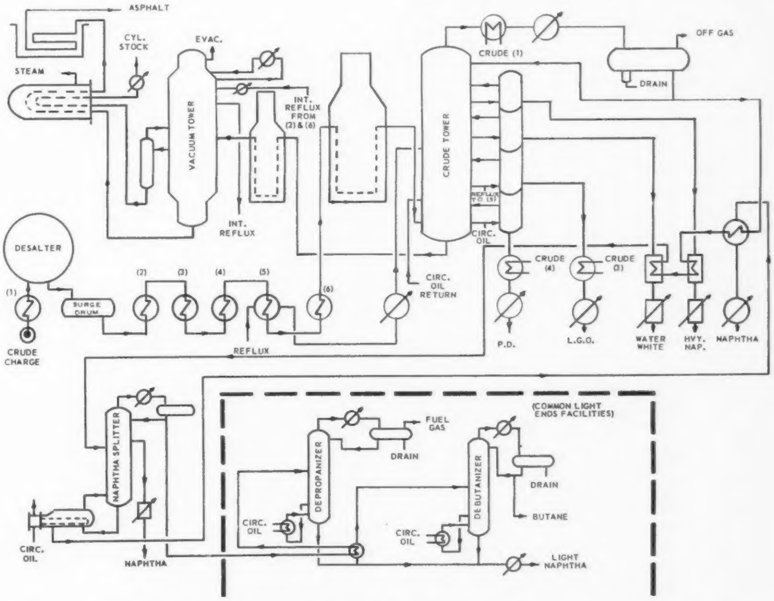

Figure 1—Flow diagram of Cleveland crude units.

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* Submitted for publication January 29, 1960. A paper presented at the 16th Annual Conference, National Association of Corrosion Engineers, Dallas, Texas, March 14-18, 1960.

effort was made to select methods which appeared to provide the necessary accuracy and reliability within a reasonable amount of time. A description of these methods is presented below, in sufficient detail to permit their use for similar studies. To provide a common basis for comparisons, capital costs are expressed in the tabulated results as 1951 dollars. Costs were adjusted to this year by the use of the Nelson petroleum refinery index (N.I.).

Furnaces. The crude and vacuum furnaces were provided originally with all carbon steel ⅜″ wall tubes and standard carbon steel return bends. It was felt that if no corrosion had been anticipated, ¼″ wall tubes would have been sufficient. There would have been no justification in eliminating the corrosion allowance in the return bends, since these were standard types for which a ¼″ corrosion allowance costs nothing extra. Unit costs in dollars per hundred foot were obtained for the ⅜″ wall and ¼″ wall tubes in the length and sizes used in the furnaces. The first four columns of Table 1 show the results of these operations. Column 5 gives the cost of corrosion allowance for each set of tubes, calculated by subtracting the total costs of ¼″ wall tubes from the corresponding costs of the ⅜″ wall tubes.

TABLE 1—Furnaces—Capital Cost of Corrosion Protection for Cleveland Crude Units

	Cost of Tubes As Installed		Cost of Tubes With 0.250″ Min. Wall		Cost of Corrosion Allowance, 1951 Dollars
	Unit Cost, \$/100 Ft.*	Total Cost, \$**	Unit Cost, \$/100 Ft.*	Total Cost, \$**	
Crude Furnaces (2 units) (Tubes and return bends—carbon steel)					
(1) Oil Radiant Tubes 128—6″ O.D. x 0.375″ M. W. x 53′-0″	427.37	20,200	296.75	14,020	6,180
(2) Oil Convection Tubes 96—6″ O.D. x 0.375″ M. W. x 20′-0″	358.63	4,800	249.02	3,340	1,460
(3) Cost of Corrosion Allowance (1) + (2)	.....	.....	.....	.....	7,640
Vacuum Furnaces (2 units) (Tubes and return bends—carbon steel)					
(4) 32 Tubes, 4″ O.D. x 0.375″ M. W. x 29′-10″	284.05	3,780	196.40	2,610	1,170
(5) 10 Tubes, 6.5″ O.D. x 0.375″ M. W. x 29′-10″	528.68	2,200	366.11	1,520	680
(6) Cost of Corrosion Allowance (4) + (5)	.....	.....	.....	.....	1,850
Total Cost of Corrosion Allowance, (3) + (6)	.....	.....	.....	.....	9,490

NOTE: Return bends are standard casting patterns, and the unit cost would increase for eliminating the corrosion allowance.
*Basis: 1958 N. I. = 208
**Basis: 1951 N. I. = 145

Towers. Three basic cost components were evaluated for towers. These are: the cost of corrosion allowance, the cost of alloy lining, and the cost of corrosion protection provided for trays. To find the cost of corrosion allowance, the total weight of the vessel was first determined. A data correlation was then used to find the unit cost of the vessel in cents per pound. For the heads and shells, separately, the total weight of the vessel was divided by the nominal thickness and multiplied by the corrosion allowance. The sum of the resulting weights was the weight of the metal representing the corrosion allowance. The weight of the corrosion allowance was next multiplied by the unit cost of the vessel, thereby yielding the total cost of corrosion allowance for each tower.

To find the cost of alloy lining for a particular tower, first the total area of the lining was calculated. Available data on unit costs of lining in dollars per square foot were applied to the lining area to give as a result the total installed cost of the lining. An exception was the lining costs for the crude towers, which was available directly as a result of an earlier study.

The cost of corrosion protection for trays was taken as the difference between the alloy tray cost and the tray cost assuming 10 gauge carbon steel as the "no-corrosion" alternate. Tray cost data were available in terms of size and alloy type. These unit cost differentials were then multiplied by the number of each size of tray in each tower. The sum of the incremental alloy costs is the total cost of corrosion protection provided for trays.

Table 2 lists for each tower the pertinent physical data, the individual corrosion protection costs (corrosion allowance, lining and tray material) and the total cost of corrosion protection.

Drums. A similar calculation method was used for drums as for towers, although a different data correlation was utilized for determining the unit cost of a drum. The sum of the corrosion allowance cost and lining cost is the total cost of the corrosion protection. Along with the pertinent physical data, Table 3 lists these corrosion costs for each drum.

Exchangers. Original equipment data were used with the procedure described here. Corrosion protection costs for exchangers consist of corrosion allowances provided for all carbon steel parts, plus the cost differential between alloy and carbon steel tube bundles.

The total cost of each exchanger was calculated as the product of the surface area, in square feet, and the unit cost, in dollars per square foot. Since exchanger unit costs vary widely, depending on several factors, it was fortunate that unit cost data pertaining to specific exchangers were available in most cases.

The shell-side and tube-side corrosion allowances were next obtained from the contractor's data sheets. These corrosion allowances were combined in arriving at a consistent corrosion allowance cost factor, which was developed for each item from an estimate provided by an established exchanger manufacturer. This cost factor is the percentage of the total exchanger cost assignable to the corrosion allowances. The individual cost factors are not accurate in an absolute sense but should be sufficient for purposes of comparative estimates. Moreover, the cost of corrosion allowances is a minor part of the total exchanger protection cost.

The total cost of the corrosion allowance was calculated as the product of the total exchanger cost (Table 4, Column 5) and the corrosion allowance cost factor (Column 8) and appears in Column 9 of this table.

Tube costs were based on the data in Table 5. The cost per square foot of surface was multiplied by the surface area to give the total cost of the tubes actually installed. Tube costs on a "no-corrosion" basis were similarly developed, assuming 16 BWG carbon steel tubes. The difference between the actual tube cost and "no-corrosion" tube cost was taken as the tube incremental cost of corrosion protection (Column 11, Table 4).

The total corrosion protection cost for each exchanger (Column 12, Table 4) is the sum of the results given in Columns 9 and 11, and the grand total is broken down by tube materials (bottom, Columns 11 and 12).

Pumps. A review of the contractor's data sheets showed that standard materials were furnished for all the crude unit pumps except those in hot oil service. Thus, the only premium paid for corrosion protection was the incremental cost of 12 percent chrome stainless steel impellers, lantern rings and packing box glands. The pump manufacturer was able to furnish cost difference information on each kind and size of part, covering a total of 22 pumps in all.

Piping. The method evolved to estimate the corrosion protection cost of the crude unit piping was a compromise, so that realistic costs could be developed in a reasonable amount of time. An item-by-item cost accounting technique was rejected as being too time consuming. Correspondingly, it was felt that a rough percentage-of-total-unit-cost approach might be greatly in error.

Since no alloy piping was provided in the crude units, all of the corrosion protection consisted of increased wall thickness. This increase in wall thickness was considered applicable only to process oil piping, and not to utility or product transfer piping. Also, cast fittings and valves could not have been obtained at a lower price if specified on a "no-corrosion" basis. Welding cost differences for heavier versus lighter wall pipe were considered small enough to be neglected.

TABLE 2—Towers—Capital Costs of Corrosion Protection for Cleveland Crude Units*

Item No.	Tower Name	Size, I.D. x Height	Corrosion Allowance, Inch	Corrosion Allowance Cost, per Tower, $	Lining Material	Installed Cost of Lining, $ per Tower	Tray Material	Incremental Cost of Trays Based On Carbon Steel, $, per Tower	Total Cost, $, Both Units
9101, 9102	Crude Towers	11′-0″ x 130′-0″	1/16	2,370	Type 405S.S. Type 321S.S. Monel	57,600	Type 410S.S. Type 321S.S. Monel	12,570 30,090 15,730	236,720
							TOTAL	58,390	
9103, 9104	Crude Tower Sidestream Strippers	3′-0″ and 3′-6″ x 71′-0″	¼	2,430	None	....	Type 410S.S.	1,540	7,940
9105, 9106	Naphtha Splitters	5′-6″ x 58′-0″	1/16	850	Monel	14,920	Monel	13,600	58,740
9107, 9108	Vacuum Towers	9′-0″, 13′-0″ and 6′-0″ x 77′-6″	Lined—1/16 Unlined—¼	2,380	Type 405S.S. Monel	18,300 4,020	Type 410S.S. Monel	12,240	73,880
					TOTAL	22,320			
9109, 9110	Vacuum Cylinder Stock Strippers	3′-6″ x 17′-0″	1/16	220	Type 405S.S.	2,280	Type 410S.S.	380	5,760
9111, 9112	Depropanizer Twr. Debutanizer Twr.	3′-6″ x 71′-9″ 4′-0″ x 48′-0″	1/16 ⅛	580 800	None None	....	Type 410S.S. Type 410S.S.	2,520 970	3,100 1,770
TOTAL COSTS				17,880		194,240		175,790	387,910

*All Costs in 1951 Dollars N. I. = 145.

TABLE 3—Drums—Capital Cost of Corrosion Protection—Cleveland Crude Units*

Item No.	Drum Name	Size, I.D. x Height	Corr. Allow., In.	Corr. Allow. Cost, per Drum, $	Lining Material	Installed Cost of Lining, $, per Drum	Total Cost, $, Both Units
6476 6478	Crude Charge Surge Drum	10′-0″ x 24′-0″	¼	2,005	....	....	4,010
6472, 6473	Crude Tower Reflux Drum (a) Shell and Heads	8′-0″ x 20′-0″	3/16, 1/16	885	Monel, Lower ½ Monel	4,640	11,050
	(b) Sump	2′-0″ x 4′-5″	3/16				
6474, 6475	Naphtha Splitter Reflux Drum	6′-0″ x 20′-0″	¼	1,325	....	....	2,650
6477	Depropanizer Reflux Drum	4′-0″ x 13′-0″	7/16	1,140	....	....	1,140
6484	Compressor Suction K. O. Drum	3′-0″ x 8′-0″	⅛	240	....	....	240
6480	Fuel Gas K. O. Drum	3′-0″ x 8′-0″	⅛	240	....	....	240
6497, 6498	Crude Desalter (Sphere)	25′-0″ Dia.	⅛	1,670	....	....	3,340
....	Barometric Drum (2)	5′-0″ x 10′-0″	¼	750	....	....	1,500
6486	Cooling Water Standpipe	2′-0″ x 8′-0″	⅛	195	....	....	195
6482	Instrument Air Receiver	3′-0″ x 8′-0″	1/16	120	....	....	120
6487	Depropanizer-Feed Water Separator (a) Shell + Heads	2′-0″ x 12′-0″	⅛	215	....	....	455
	(b) Sump	1′-0″ x 4′-0″	....	....	Solid Monel	Cost Diff. 240	....
6460	Debutanizer Reflux Drum	5′-0″ x 12′-0″	0	....	....	....	....
	Debut. Refl. Drum Sump	1′-6″ x 3′-7/16″	0	....	20% Clad Monel	480	480
6459	Pulsation Snubber (Special)	2′-0″ x 6′-6″	⅛	275	....	....	275
6466	Pulsation Snubber	1′-6″ x 6′-0″	¼	335	....	....	335
	Total Costs (Both Units)	....	....	16,030	....	10,000	26,030

*All costs in 1951 Dollars (N. I. = 145).

The piping cost differentials were based on wall thicknesses actually provided, compared to minimum thicknesses on the "no-corrosion" basis. These comparisons are specifically listed in Table 6, Notes (1) and (2). The unit costs shown in Table 6 were obtained for pipe, welding elbows, welding tees and welding reducers in pipe sizes from 2″ through 24″. Pipe sizes under 2″ were omitted, since the wall thicknesses in this category are governed mainly by mechanical strength considerations.

The best source of information on piping quantities was found to be the refinery inspection records and the fabricator's spool drawings. Accordingly, the inspection classification of fabricated pipe was adopted in making quantitative estimates. Thus, an item of fabricated pipe is classed as a spool, bend, header or header bend. Each of these classes contains one or more of the components for which the unit costs of Table 6 had been obtained. From this point on, the procedure was as follows:

1. A complete listing of fabricated pipe by class and size was made for one unit and the common light-ends facilities. The size groupings were simplified by neglecting reducers and by listing each item by the largest pipe size it contained.
2. For each class and size of fabricated pipe, it was desired to determine the average number of each type of fitting (pipe, welding elbow, etc.) occuring in an item. This average frequency concept was assumed to be valid under the restrictions of this system. Fabricated pipe items were selected at random from the fabricator's spool drawings, except for sizes above 8″. A record was kept of the approximate number of feet of pipe and the number each of elbows, tees and reducers. This data was tabulated against pipe size and item class. For sizes above 8″, a more thorough tabulation was made because of the small number of such items installed.
3. The average frequency of occurrence of each type of fitting was determined by dividing the total number of fittings in a size-class (for example, 4″ header bends) by the number of items in that size-class, as found from the inspection item tabulation. For each size-class, there emerged a composite item containing the average pipe length and the average number of each type of welding fitting. These composite items are listed in Table 7.
4. The unit cost differentials from Table 6 were multiplied by their corresponding values for the average frequency of occurrence, for each size and type of fitting. The resulting cost differentials were then totaled separately for each composite item, and the sum was multiplied by the number of items installed. This gave the average corrosion protection cost for each size-class of fabricated pipe. Total costs were then found for each pipe size and, finally, for all of the piping. Table 7 summarizes these breakdowns and lists the totals.

Miscellaneous. Cost data for the inhibitor injection and ammonia storage equipment were fully covered in capital expenditure records. All of this cost was designated as corrosion protection, although other process benefits are also derived from the use of this equipment.

Distribution of Capital Costs

In reviewing the significance of the cost data given in Tables 1 through 7, it is in order to examine first the cost comparisons within each class of equipment.

Furnaces. The $9,500 cost of corrosion allowance for all furnace tubes reflects the minimum protection provided for furnaces in the original job. This minimum protection was judged to be adequate on the basis of a forecast of sweet-crude operation for the period immediately following the original

TABLE 4—Exchangers—Capital Cost of Corrosion Protection for Cleveland Crude Units

No.	Exchanger Service	No. of Shells	Size, Sq. Ft.	Total Cost	Corrosion Allowances: Shell Side In $^1/_{16}$″	Corrosion Allowances: Tube Side In $^1/_{16}$″	Corrosion Allowances: Factor %	Corrosion Allowances: Cost $	Tube Material*	Cost of Tube Corrosion Protection	Total Corrosion Cost
1	Vac. P.A. Reflux—Hot Crude Exchs.	6	1,800	33,400	1	1	1.5	500	CS	680	1,180
2	Vac. P.A. Reflux—Cold Crude Exchs.	2	677	7,800	2	2	2.0	160	CS	90	250
3	Crude Tower O.H.—Crude Exchangers	8	1,392	38,600	3	2	2.7	1,040	CS	700	1,740
4	Crude Tower O.H. Condensers	8	2,165	61,600	3	3	3.0	1,850	AA	12,790	14,640
5	Crude Tower P.A. Reflux Trim Coolers	2	394	3,700	2	3	2.3	90	AA	580	670
6	Crude Twr. Intermediate Reflux—Crude Exchs.	2	1,350	9,700	1	1	1.5	150	CS	170	320
7	No. 4 Sidestream—Crude Exchangers	2	1,136	8,000	1	1	1.5	120	CS	140	260
8	No. 3 Sidestream—Crude Exchangers	2	1,136	8,000	1	1	1.5	120	CS	140	260
9	No. 3 Sidestream Coolers	2	370	4,100	2	3	2.3	100	AA	550	650
10	No. 4 Sidestream Coolers	2	528	5,700	1	3	2.0	110	AA	780	890
11	Nap. Splitter Bottoms—Feed Exchangers	2	534	4,900	1	1	1.5	70	CS	40	110
12	Reforming Naphtha Coolers	2	850	7,000	2	3	2.3	160	AA	1,260	1,420
13	Naphtha Splitter O.H. Condensers	4	1,850	26,300	3	3	3.0	790	AA	5,460	6,250
14	Naphtha Splitter Reboilers	2	1,365	11,200	2	2	2.0	220	CS	110	330
15-16	Depropanizer Bottoms—Feed Exchangers	2	271	3,400	2	2	2.0	70	CS	20	90
17	Depropanizer Bottoms Cooler	1	850	4,000	2	3	2.3	90	AA	630	720
18	Compressor Jacket Water Cooler	1	243	1,400	1	3	2.0	30	AA	180	210
19	Depropanizer O.H. Condenser	1	1,538	6,600	2	3	2.3	150	AA	1,140	1,290
20-21	Depropanizer Reboilers	2	829	6,700	2	2	2.0	130	CS	70	200
22	Vac. P.A. Reflux Trim Coolers	2	527	5,700	1	3	2.0	110	AA	780	890
23	Vac. Cylinder Stock Coolers	2	522	5,600	1	3	2.0	110	AA	770	880
24	Vac. Top Reflux Coolers	4	1,240	21,100	1	3	2.0	420	AA	3,670	4,090
..	Asphalt Cooler Coil	1	....	....	....	....	....	910	CS	....	910
25	No. 4 Sidestream P.A.—Crude Exchangers	2	1,350	13,400	2	2	2.0	200	CS	170	370
26	No. 4 Sidestream (P.D.) Coolers	2	521	8,100	2	4	2.5	150	AA	770	920
27	Debutanizer Reboiler	1	148	2,300	2	2	2.0	40	CS	10	50
28	Debutanizer O.H. Condenser	1	2,240	7,400	2	4	2.5	140	AA	1,650	1,790
	Total Cost—Car. Stl. Tubes							......		2,340	6,070
	Total Cost—Ant. Adm. Tubes							......		31,010	35,310
	Total Cost—All Exchangers							8,030		33,350	41,380

*CS = Carbon Steel. AA = Antimonial Admiralty.

TABLE 5—Exchanger Tube Base Costs for Determining Cost of Corrosion Protection

Tube O.D., Inch	Wall Thickness BWG	Price per 100 Ft. As of Dec. '58 N. I. = 208	Price per Sq. Ft. As of 1951 N. I. = 145	Cost Diff. per Sq. Ft. N. I. = 145
¾	16	$25.76	$0.917	....
¾	13	26.92	0.957	+0.040
1	16	29.05	0.775	....
1	12	31.40	0.838	+0.063

1. Carbon Steel Tubes: ASTM Gr. A-83 or A-179, 16-Ft.
   Tube cost differences based on 16 BWG wall as minimum requirement.
2. Antimonial admiralty tubes:
   Basis: (Feb. 1951) $0.4933/Lb. For 1500-Piece Lots, ¾″ x 14 BWG x 16′ Tubes.
   Min. Cost per Foot—$0.316 @ 15,430 Lbs. per 1500 pieces.
   Max. Cost per Foot—$0.333 @ 16,200 Lbs. per 1500 pieces.
   Average Cost per Foot—$0.325.
   Average Cost per Sq. Ft.—$1.656.
   Cost differential, based on ¾″ x 16 BWG x 16′ carbon steel— +$0.739 per sq. ft.

TABLE 6—Piping Cost Differentials on Wall Thickness Required for Corrosion Allowance

Nominal Pipe Size, Inches	Pipe, $/Ft.	Welding Elbows, $ Each	Welding Tees, $ Each	Welding Reducers, $ Each
2	0.114	0.29	0.00	0.83
3	0.202	0.68	2.05	1.37
4	0.293	1.01	3.27	1.96
6	0.647	2.16	5.73	3.76
8	0.967	4.08	10.62	8.70
10	0.941	8.66	18.03	14.04
12	1.323	13.30	21.50	15.80
14	1.099	19.33	40.90	32.30
16	1.246	28.37	56.00	40.70
18	1.421	37.67	76.30	68.00
24	1.862	49.50	111.70	110.10

UNIT COST DIFFERENTIALS, 1951 DOLLARS (N. I. = 145).
NOTE: (1) Differential costs on all welding fittings based on "extra strong" versus "standard" wall thickness.
(2) Piping differential costs based as follows:
2″–8″: Sched. 80 vs. Sched. 40
10″: Sched. 60 vs. Sched. 40
12″: 0.562″ wall vs. 0.406″ wall
14″ and Larger: 0.500″ wall vs. 0.375″ wall

start-up. Since that time, alloy renewals have been necessary, but many of the original carbon steel tubes are still in service, and carbon steel has proved to be a reasonable choice. However, a question exists whether an initial installation of 5% chrome moly alloy tubes might have been justified in the light of the high cost of alloy tube renewals. As yet, no study has been attempted in order to answer this question.

Towers. By far the largest portion of the capital cost of corrosion protection went into towers. As Table 2 indicates, alloy lining and alloy internals were provided for larger towers, which are the towers for which, in general, alloy is most readily justified. The lining and trays accounted for nearly all of this cost, which was divided equally between them. Over 60% of the total corrosion protection cost of towers is in the two crude towers. The vacuum towers and the naphtha splitters together account for 34%. The remaining 6% is divided among the side-stream strippers, the depropanizer tower and the debutanizer tower. As a class, towers accounted for $388,000, or over 77% of the total cost of corrosion protection for all equipment.

Drums. The corrosion protection costs for drums are small, amounting to $26,000 for 19 drums. Corrosion allowances represented $16,000 of this sum. The Monel lining installed in the two crude tower overhead accumulators cost $9,200, or 35% of the total.

Exchangers. No alloy was provided for exchangers in the original job, except for inhibited Admiralty tubes in coolers and and condensers, which represented 75% of the total corrosion protection cost for exchangers. The additional wall thickness provided in carbon steel tubes accounted for only 6% of the total. The remainder of the cost is taken up by the estimated corrosion allowances. For the 68 exchangers, the $41,000 total cost of corrosion protection comes to approximately $600 per exchanger. The range of costs, per unit, was from $45 to $1,830.

Pumps. Pumps were the least costly class of equipment from a corrosion viewpoint. Although no alloy protection was built into pumps handling such corrosive materials as light naphtha, maintenance has not been excessive on pumps. The total differential cost of the 12% chrome stainless steel parts provided for hot oil pumps was $1,300.

Piping. No alloy piping was provided in the original job. The corrosion protection thus consisted of wall thickness in excess of the minimum requirement, as defined in note (2) of Table 6. The

TABLE 7—Fabricated Piping—Capital Cost of Corrosion Protection—Cleveland Crude Units

Type of Fabricated Assembly	COMPONENTS—QUANTITY	NOMINAL PIPE SIZE 2″	3″	4″	6″	8″	10″	12″	Over 12″ See (Specific Notes Below)		
Spools	Pipe. Avg. Ft./Spool	1	32.5	3.5	51.5	40	8	....	18″	19	
	Total No. Spools	48	133	92	90	24	4	....		2	
Total Cost: $5,090 →	Cost of Diff. Wall Thick.	5	894	97	3,000	929	30	....		54	
Bends	Pipe, Avg. Ft./Bend	15.4	22.4	19.1	20.0	26.0	19.3	15	18″	90	
	Ells, Avg. No./Bend	0.87	0.39	0.84	0.90	1.17	2.60	2		1	
	Reducers, Avg. No./Bend	0.055	0.12	0.093	0.10	0.28	0	0		0	
	Total No. Bends	110	256	287	242	91	20	2		2	
Total Cost: $11,590 →	Cost of Diff. Wall Thick.	240	1,315	2,039	3,782	2,973	814	93		331	
Headers	Pipe, Avg. Ft./Header	4.4	9.9	6.5	20.5	15.2	2.0	8	18″	19.7	
	Ells, Avg. No./Header	0	0.50	0.15	1	0	0	0		0	
	Tees, Avg. No./Header	1.20	0.75	1.23	5	3.33	4	2		1	
	Reducers, Avg. No./Header	0.40	1.0	0.62	0	0	0	0		0.67	
	Total No. Headers	9	36	56	36	14	4	2		4	
Total Cost: $4,100 →	Cost of Diff. Wall Thick.	8	199	430	1,590	301	364	107		600	
Header Bends	Pipe, Avg. Ft./Hdr. Bend	12.9	15.9	17.7	17.4	14.1	16.8	....	14.3	60	32
	Ells, Avg. No./Hdr. Bend	0.60	0.58	0.81	0.95	1.50	1.50	....	2.67	4	0
	Tees, Avg. No./Hdr. Bend	1.40	1.31	1.11	1.24	0.90	0.50	....	0.33	4	0
	Reducers, Avg. No./Hdr. Bend	0	0.38	0.40	0.14	0.70	0	....	0	0	0
	Total No. Hdr. Bends	34	137	130	114	28	6	....	6	2	4
Total Cost: $7,700 →	Cost of Diff. Wall Thick.	59	961	1,454	2,390	1,061	227	....	485 (14″)	824 (16″)	238 (24″)
	TOTAL COSTS By Pipe Size →	310	3,370	4,020	10,760	5,760	1,540	200	490 (14″)	820 (16″) 980 (18″)	240 (24″)
$28,480	← All Piping	....	....	....	....	....	....	....			

NOTE: (1) See Table 6 for unit costs of pipe and welding fittings. (2) All costs in 1951 dollars (N.I. = 145).

total corrosion protection cost was $28,500 or 63 cents per barrel per stream day of rated capacity. As in the case of furnace tubes, the corrosion allowance approach has proved to be entirely economical. And in like manner, a continuing (though limited) program of 5% chrome-moly alloy renewals has been and is now in effect.

Table 8 permits comparison between the different classes of equipment of the individual total corrosion protection costs. Tower lining, trays and cooler and condenser tubes accounted for 80% of the total cost. Corrosion allowances on carbon steel, though generally liberal, were only 20%. It is of further interest that the corrosion protection for towers amounted to over one-half the total cost of the towers, whereas the corrosion protection for pumps amounted to less than 1% of the cost of the pumps. The grand total of the corrosion protection cost for both crude units was $500,870.

TABLE 8—Cost of Corrosion Protection

	Cost of Corrosion Allowance	Cost of Alloy Materials	Total Cost of Corrosion Protection	Per Cent of Equipment Cost
Furnaces (4)	$ 9,490	....	$ 9,490	3.4
Towers (12)	17,880	$194,240	387,910	51.0
Trays for above towers	....	175,790		
Drums (19)	16,030	10,000	36,030	....
Exchangers (68)				
C. S. Tubes (34)	2,340	....	41,380	8.4
A. A. Tubes (34)	....	31,010	....	....
Other Parts	8,030	....	....	....
Pumps	....	1,330	1,330	0.7
Piping				
2″ and 3″	3,680	....	....	....
4″	4,020	....	....	....
6″	10,760	....	....	....
8″	5,750	....	....	....
10″ and larger	4,270	....	....	....
Total	(28,480)	....	28,480	....
Special Equipment	....	....	6,250	....
TOTALS	$82,250	$412,370	$500,870	....

Evaluation of the Total Capital Cost of Corrosion

The cost of corrosion protection determined for each class of equipment represents an implicit charge by the contractor in the original job and in subsequent capital expenditures. For this reason, it can not be inferred that a reduction in corrosion protection investment would necessarily have resulted in a proportionately lower cost. The actual cost decrease is subject to variation in a contract job depending on specific agreements which may exist. The capital cost of corrosion is in this sense a hypothetical number; yet it represents a rational, average estimate of the additional amount required to pay for the built-in corrosion protection. The total cost, $500,870, is the original value of the corrosion protection provided *as such.* It does *not* include the value of corrosion protection automatically provided because of other considerations which govern, such as mechanical efficiency and the availability of standardized designs. Corrosion protection of this kind costs nothing extra.

The total cost of corrosion can be regarded from several standpoints: as a number in itself of basic importance; as an intangible contributing to the burden of money requiring financing; and as an amount of money to be treated as a capital recovery. For the reasons given in the introductory paragraphs, the basic cost is in itself considered as providing an adequate result for this portion of the study.

Maintenance Cost of Corrosion

Several approaches were tested in the effort to develop the maintenance cost values associated with corrosion alone. Consideration was given to the possibility of reviewing refinery work orders, in order to extract all the detailed expenditures. This approach was abandoned because of various practical difficulties. As the study progressed, it became apparent that the corrosion part of the total maintenance cost could be isolated best by the use of estimating techniques relying considerably on general experience. In applying this method, repair and renewal costs have been assumed to be closely related to the actual corrosion costs, even though some repairs involve corrosion distantly or not at all. The purpose was also served of defining specific areas deserving the most attention, with the object of indicating possible improvements in the concentration of maintenance efforts.

Cost Estimating Methods

The breakdown of maintenance costs was carried out by a method of approximation. Total maintenance costs were first obtained, using refinery monthly cost records to develop data on an annual basis. The maintenance year is from September to August, since the units originally went on stream in September, 1952.

To determine the breakdown of maintenance costs among the different types of process equipment, the following procedure was used:

1. A thorough review of refinery inspection reports was made, covering the five year period following the original start-up.
2. All repairs and renewals in a given year were listed by the specific type of work done (for example, repairs to vacuum tower trays, renewal of furnace components, retubing of bundles in the crude tower overhead condensers). For each type of job, the number of items included and the number of repairs were listed.
3. The specific work items from step 2 were then relisted under the headings: exchangers, furnaces, vessels and piping. Under each of these headings the specific work items were grouped into classes to which unit costs of repairs and renewals could be assigned.
4. Unit costs were estimated for each class of work. Where major doubt existed as to the area of magnitude of a cost, the refinery was consulted. These unit costs were then multiplied by the number of items listed under each class for each year. The result gave the total annual dollars spent for each class of work.
5. For each equipment heading, the individual total annual costs by class of work were totalled. This gave the total annual cost of repairs and renewals by type of equipment.
6. The "general" maintenance cost was taken as the difference between this total and the sum of the process equipment maintenance costs.

Assuming that estimating errors tend to cancel, the maintenance cost breakdown obtained by the above method should be reasonably valid for the purpose of showing the relative effect on maintenance of each category of process equipment.

Distribution of Maintenance Costs

Maintenance costs for a refinery unit can be divided into two categories: (1) costs resulting from the deterioration of process equipment, and (2) general costs. Figure 2 shows the total annual maintenance costs for the first five years of operation. These costs are broken down by types of process equipment, with the remainder designated as general costs. The costs assigned to process equipment derive from repairs and renewals made for any of the following reasons:

1. Low and high temperature forms of corrosion.
2. High temperature deterioration of strength.
3. Inadequate mechanical design for existing service conditions.
4. Fouling and plugging.

Each of the above considerations has shown up as an important factor in the maintenance cost picture. Table 9 summarizes the pattern of process repairs and renewals through 1957. This pattern is the outcome of the well known forms of corrosion present in most crude units, coupled with the scheme of corrosion protection as provided originally. The major vessels were provided with complete alloy protection, and no additional installation of lining has been necessary. However, renewals and repairs to minor equipment have continually been a large maintenance cost. The main part of this cost is associated with low temperature equipment, where acid attack by hydrogen chloride and hydrogen sulfide in aqueous solution has been severe. To a lesser extent repairs and renewals have also been caused by high temperature sulfur attack. The renewals resulting from low temperature acid corrosion became heavy in the first three years of operation, while only in recent years has high temperature sulfur attack become a serious concern. During this period, crudes charged to these units were mildly corrosive Illinois and Midcontinent types. In addition, corrosion has been intensified by the high crude throughputs maintained during most of these years.

As a class, exchangers have been the highest maintenance cost item. Perhaps 90% of the exchanger maintenance cost has resulted from corrosion and fouling occurring in the crude tower overhead exchangers and condensers. Seven Monel tube bundles have been installed (there are 16 shells in all), and a great many more bundles have been renewed with carbon steel or Admiralty tubes. Some retubing has been necessary in the naphtha splitter condensers, reboilers and feed exchangers. Because of high-temperature sulfur attack, the steam generators have periodically required alloy and carbon steel renewals.

Furnace maintenance has been the second largest process equipment cost item. Both of the crude furnaces, which are vertical tube types, have required repairs and renewals to a similar extent. Tube renewals account for the major part of this cost, followed by repairs to the reradiating cones and cone supports. The principal tube problems have been flame impingment, bowing and tube end erosion corrosion.

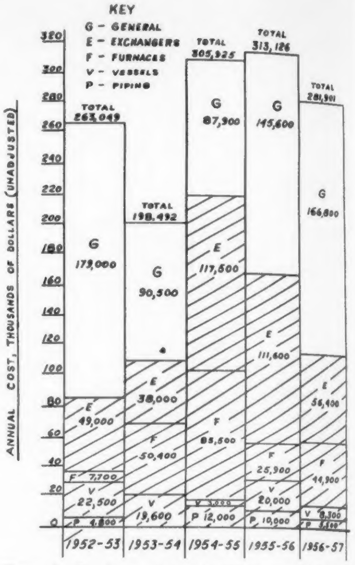


Figure 2—Total annual maintenance costs, Cleveland crude units.

Vessel maintenance has consisted mostly of repairs to tower internals necessitated by deficiencies not connected with corrosion. The provision of extensive alloying in the original design of the major towers has served to keep most of the vessels free of any serious corrosion.

Piping has been a minor maintenance item, averaging about 5% of the total maintenance cost. Through 1957, corrosion was serious only in the vacuum tower bottoms piping. More recently, some renewals of other high temperature service piping have been required, apparently as a result of mild sulfur attack all during the life of this equipment.

Maintenance Cost Trends

A useful byproduct of a maintenance cost-of-corrosion study is the opportunity provided to analyze trends. The maintenance requirements have generally

TABLE 9—Areas of Major Maintenance Cost (Process Equipment)

Year	Exchangers	Furnaces	Vessels	Piping
1952–53	Retubing of crude tower O.H. exch. and condenser bundles.	Repairs to cone sheets. New cone tip hangers.	Repairs and repositioning upset trays	Expansion joint failures on heater outlet lines.
1953–54	Increased retubing in crude tower O.H. system. Bundles rotated.	Repairs to cone insulation and supports. Tube renewals.	Repairs and repositioning-upset trays.	Minor renewals.
1954–55	Increased retubing in crude tower O.H. system. Some Monel installed.	Heavy renewals of tubes and cone parts. Insul. & refract. repairs.	Minor repairs and renewals.	Nipple replacement program. Minor piping renewals.
1955–56	Retubing in crude twr. O.H. system about the same as in 1954–55.	Decreased renewals of tubes and cone parts. Miscellaneous repairs.	Desalter bottoms lined. Tray repairs in crude tower.	Piping renewed-acid attack and high temp. sulfur attack.
1956–57	Miscellaneous retubing with carbon steel and brass. Repairs to condenser shells.	Continuing tube renewals. Installation of tube support guides.	Upset trays repaired. Crude tower trays braced up.	Minor renewals, mostly due to high temp. sulfur attack.

been alike for both crude units. Table 9 presents the major trends associated with corrosion for each class of process equipment. During the first two years of operation, very few repairs because of corrosion were necessary. During the third and fourth years, heavy alloy renewals were made in the crude tower overhead systems and in the crude furnaces. Since that time, furnace tube renewals have continued, and more hot oil piping has been reaching the corrosion limit. Repairs and renewals because of cooling water corrosion have been a major expense.

The data in Figure 2 illustrate that the total maintenance cost can show a distinctly different trend from the cost of process equipment repairs and renewals. In general, the total maintenance cost tends to be a constant figure. This relationship arises from the practice of deferring non-urgent work, when the demands on facilities and manpower are heavy because of needed process equipment repairs and renewals.

Trends forecasted two years ago based on the maintenance cost data presented here have generally been confirmed, as illustrated by the following examples:

1. Exchanger bundle renewals were predicted to decrease over the subsequent three to five years and then remain at some minimum level, with alloy continuing to be installed to meet severely corrosive conditions. (This has proved true so far, although no additional alloy has yet been required.)

2. Renewals of carbon steel furnace tubes were expected to increase for a time until the necessary alloying became completed. (Confirmed; some alloy renewals will continue to be required.)

3. Piping was expected to become a major renewal cost, as carbon steel lines in hot oil services reached their limits. (This trend has developed as expected; crude furnace outlet and transfer lines in both units have approached or reached their corrosion allowance limits.)

4. Little change in vessel corrosion maintenance was predicted. (Since that time no change has been observed.)

Results of Maintenance Cost of Corrosion Study

Corrosion costs make up varying portions of the repair and renewal costs and of the "general" costs. It would be time-consuming and laborious to calculate precisely the corrosion fraction of each maintenance cost. Existing data breakdowns are not well suited for the purpose of segregating corrosion costs. For these reasons, it was decided to use estimated corrosion cost percentages derived from a knowledge of the maintenance and corrosion history of the crude units.

Table 10 gives the estimated cost factors for exchangers, furnaces, vessels and piping. These factors have changed from year to year. Factors for "general" maintenance costs were obtained by halving the overall equipment cost factor. The total annual corrosion cost yielded by these factors was then adjusted to 1957 dollars. Based on a yearly average of 18,100,000 barrels of crude run for both units, the corrosion portion of the average maintenance cost was found to be 0.96 cent per barrel of crude, or currently about 1 cent per barrel.

Corrosion Control Operating Costs

Included under corrosion control operating costs are the costs associated with the use of corrosion control chemicals. These chemicals include the ammonia and inhibitor used in the crude tower overhead systems and a portion of the chemicals used in treating cooling water.

All of these costs were assembled from directly available data. Ammonia and inhibitor costs were obtained from monthly records and represent conservative averages. The corrosion control portion of the cooling water chemical treatment had been previously determined in a separate study. Table 11 summarizes the operating cost data. The total corrosion control operating cost amounts to 0.16 cent per barrel of crude.

Actual Corrosion Costs

While it has been stated that the scope of this study does not include developing an estimate of the cost of corrosion for the entire refining operation, the basic costs can be converted to actual costs pertaining to crude units alone. Using the methods and assumptions described below, the total actual cost of corrosion was found to be 2.0 cents per barrel.

1. *Capital Cost of Corrosion Protection*

Depending on the method used, the basic total capital cost can be translated, by applying economic factors, into any of several values representing the actual cost of corrosion protection. For comparison purposes an example is given here using a capital recovery method. Assuming sum-of-digits depreciation over 10 years at a 10% worth of money rate and a 52% Federal Income Tax factor, the \$500,870 base cost becomes an actual present-worth cost of \$312,000. To bring the actual cost to a current dollar basis, an inflation factor of 1.5 results in a \$468,000 actual cost in current dollars. This amounts to 0.19 cent per barrel of crude run, using the equipment corrosion-protection life figures from Table 12.

2. *Maintenance Cost of Corrosion*

The 1 cent per barrel cost determined in this study reflects direct charges only. Assuming that labor represents 50% of this cost, overheads are included by applying a factor of 1.5 to the corrosion maintenance cost, giving 1.5 cents per barrel as the adjusted maintenance corrosion cost.

3. *Corrosion Control Operating Costs*

A fair estimate of the cost factor for overhead associated with chemical costs is 100%. This results in an adjusted corrosion control cost of 0.32 cent per barrel.

Conclusions

The direct cost of corrosion for the Cleveland crude units was found to be 1.36 cents per barrel. This cost includes corrosion costs associated with maintenance, the capital cost of built-in corrosion protection and operating costs consisting mainly of corrosion control treatment. It does not include the cost of product volume or quality losses resulting from unscheduled shutdowns, nor does it include losses due to equipment fouling. Overheads and capital cost factors, assumed for illustration only, result in a total actual cost of 2.0 cents per barrel.

The components which make up the 1.36 cent per barrel figure are given in Table 12. The capital costs are based on \$500,870 which in turn is broken down for an average crude throughput of 18,100,000 barrels per year. The breakdown of this cost by class of equipment is in turn modified by the estimated life

TABLE 10—Corrosion Portion of the Maintenance Cost, Cleveland Crude Units

Group		YEAR				
		1952–53	1953–54	1954–55	1955–56	1956–57
Furnaces	Cost Factor, %	0	80	90	70	70
	Cost, \$	0	40,000	77,000	18,000	31,000
Vessels	Cost Factor, %	10	20	75	50	20
	Cost, \$	2,000	4,000	2,000	10,000	2,000
Exchangers	Cost Factor, %	90	90	90	90	90
	Cost, \$	44,000	34,000	106,000	100,000	51,000
Piping	Cost Factor, %	0	100	100	100	100
	Cost, \$	0	1,000	12,000	10,000	6,000
General	Cost Factor, %	27	37	45	40	40
	Cost, \$	48,000	34,000	40,000	60,000	65,000
TOTAL COSTS, \$		94,000	113,000	237,000	198,000	155,000
TOTAL COSTS IN 1957 \$		116,000	129,000	264,000	204,000	155,000

AVERAGE ANNUAL COST, 1952–57 (1957 \$) \$174,000
AVERAGE ANNUAL CRUDE RUN, BARRELS 18,100,000
AVERAGE MAINTENANCE CORROSION COST .... 0.96 cent per barrel (1957 \$)
1.0 cent per barrel (current)

TABLE 11—Corrosion-Control Operating Costs, Cleveland Crude Units

Chemical	Cost, Cents per Barrel of Crude Run
Ammonia	0.045
Inhibitors	0.095
Corrosion-control portion of cooling water treatment	0.020
TOTAL	0.160

TABLE 12—Current Base Cost of Corrosion

Item	Costs, Dollars per Thousand Barrels of Crude Run					
	Capital		Maintenance Cost*	Operating Cost	Total Cost	Percent of Total
	Life, Yrs.	Cost				
Furnaces	7	0.09	2.53	....	2.62	19.2
Vessels	15	1.53	1.05	....	2.58	19.0
Exchangers	10	0.24	5.19	....	5.43	39.8
Pumps	20	0.004	0.10	....	0.10	0.7
Piping	12	0.13	0.55	....	0.68	5.0
Chemicals	10	0.04	....	1.60	1.64	12.0
General	....	....	0.58	....	0.58	4.3
		2.03	10.00	1.60	13.63	100.0

*These costs include $3.13 of general corrosion-caused maintenance cost broken down according to the following proportions: furnaces, $0.45; vessels, $0.80; exchangers, $1.00; pumps, $0.10; piping, $0.20; general, $0.55.

of the corrosion protection for each class. The maintenance cost breakdown is an average from the data in Table 10, converted to current dollars.

The largest single corrosion cost in these crude units has been repairs and retubing of exchangers. Furnace and vessel repairs are next in order. Chemicals consumed in cooling water treatment, ammonia and inhibitor are the fourth major corrosion-cost items.

It appears that the detailed study method is the most practical route to an accurate appraisal of corrosion costs when this method incorporates some time-saving simplifications. With this approach it has been learned that the actual corrosion costs for the Cleveland crude units have been lower than previous estimates indicated. Also, the relative magnitudes and importance of the various corrosion-cost components have been determined. It is anticipated that some of the techniques evolved in this study may prove of value in future corrosion-cost studies.

DISCUSSION

Question by H. Howard Bennett, Mobil Oil Co., Paulsboro, New Jersey:

Have you determined the percentage of your maintenance cost that results from inspection? This cost would include inspection labor, removal of insulation, opening of equipment, scaffolding, cleaning, etc.

Reply by Norris J. Landis:

No inspection cost data were available, and no attempt was made to isolate this cost from the total labor cost.

Question by A. S. Couper, Whiting, Indiana:

Should a cost be applied for desalting?

Reply by Norris J. Landis:

We feel that a cost should be applied, but that only a portion of the desalting cost normally should be attributed to corrosion. A considerable part of this cost is identifiable with improvements in the process, for example, better heat transfer and lower pressure drops. In this study, the corrosion portion of the desalting cost was not specifically determined. An estimate of this cost would, in our case, be purely arbitrary and more likely to be misleading than meaningful. One reason is that we do not know what tangible benefit (if any) desalting is conferring in corrosion reduction. Process benefits probably are the main justification for desalting in these crude units.

Question by Joseph P. Picarazzi, Cities Service Refining Corp., Lake Charles, Louisiana:

Exchanger maintenance costs were shown to be a high figure. Is alloy upgrading in exchangers counted a maintenance cost?

Reply by Norris J. Landis:

Our feeling is that, for study purposes, any alloy upgrading involving no additional facilities is logically classified under maintenance cost. Accordingly, the Monel renewals in the crude tower overhead exchangers and condensers are considered to be maintenance costs.

References

1. Report of Panel on Cost of Corrosion in Refinery Equipment. API Subcommittee on Corrosion, 1953-1954.

Any discussion of this article not published above will appear in June, 1961 issue.

Cathodic Protection of Water Treatment Plants★

By F. O. WATERS

Abstract

Corrosion processes confronting water treatment plants are enumerated. Problems encountered in the installation, testing and operation of cathodic protection for rapid sand and pressure type filters are discussed. A six-year operating experience indicates the value of cathodic protection in both types of treatment plants. 5.2.1

Introduction

SAN DIEGO'S Alvarado Filtration Plant was constructed 10 years ago with a capacity of 66 million gallons per day. The water detention time in the mixing basins at capacity flow is 46 minutes, with a two-hour time period allowed in the settling basins. Eight filters are found in the system, each of which has 1,933 square feet of surface with a filter rate of 3 gallons per square foot per minute.

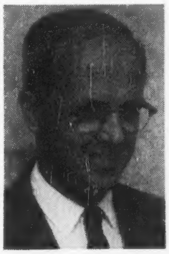
The plant is located 530 feet above sea level and allows gravity flow for the water leaving the plant. Complete chemical treatment and laboratory facilities for water treatment, testing and control are provided.

Although the plant was designed for 66 million gallons per day, the average 24 hour consumption in the summer will seldom fall below plant capacity, and the maximum is almost 100 million gallons per day.

Severe corrosion was found in this plant in December, 1951. As a result an attempt was made to install cathodic protection. These early efforts failed primarily because of improper insulation of joints in the anode circuit and because of the method used to anchor the anodes to the basin walls. In December, 1952, half inch deep pits were found in the 5½-inch diameter steel drives. Cathodic protection was then installed and first started in March, 1953.

Special Problems

Many complex problems are found in any large plant and Alvarado is no exception. This discussion will be limited to the corrosion difficulties in the chemical treatment basins only. In addition to the ordinary minerals found in Colorado River Water, the metal in these basins comes in contact with quantities of chlorine, quick lime, ferric sulfate, carbon and soda ash.



About the Author

F. O. WATERS is with the City of San Diego (California) Utilities Department. He is a graduate electrical engineer, having received his B. S. degree from Kansas State College. After graduation he worked for the California Ship Building Corp., and later in the Research Department of the Southern California Gas Company where he served as corrosion engineer. He moved to his present position in 1952. Mr. Waters is a registered professional electrical engineer, and is a member of the American Water Works Association and the NACE.

The water has a resistivity that changes during the year from 1,100 to about 1,800 ohm centimeters. There is a total of approximately 7,400 square feet of metal in the mixing basins and slightly more metal in the settling basins.

Insulating Material

To prevent the same failures that occurred in the original installation, a long series of accelerated tests on insulating material were undertaken.

The original installation ruled out the use of joints insulated with rubber and friction tape. Accelerated tests soon indicated the weakness in using mastic, grease, "plastic" tapes, or the brushed on rubber compounds. The test indicated that a combination of a first layer of rubber putty and a final layer of polyvinyl tape was superior to other insulating compounds. Minnesota Mining and Manufacturing Company's Scotch-fil and Scotch No. 33 were used in the final installations.

Figure 1 shows the basins on which protection was installed. The upper portion of the picture shows the settling basin with the traveling chains. One chemical mixing basin is directly below. The drives and paddles can be seen in this portion of the picture.

Calculations were made to determine the current output required to give various current densities for the metallic structures in each basin. Tests were then made with temporary stations which indicated that minimum potential—0.85 volt of the steel with respect to a copper sulfate electrode could be obtained with 4 milliamperes current density per square foot of steel surface.

Permanent installations were made with the rectifier unit located in the control houses. One house is shown in the upper center of Figure 1.

A total of 8 cathodic protection sta-

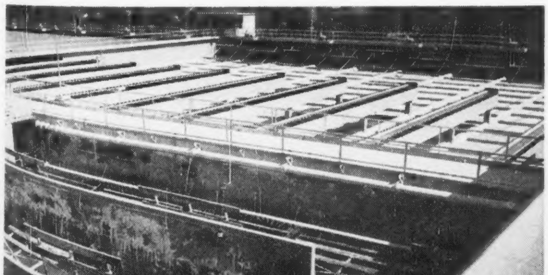


Figure 1—Basins where cathodic protection was installed.

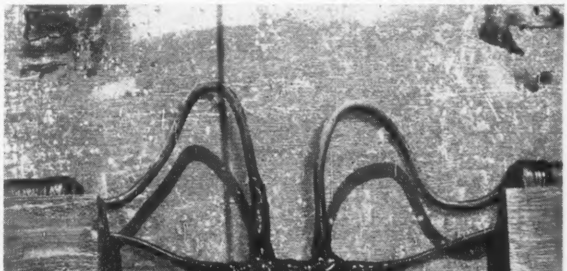


Figure 2—Mounting of graphite anodes.

★Submitted for publication November 9, 1959. A paper presented at a meeting of the Western Region, National Association of Corrosion Engineers, Bakersfield, California, Sept. 29-Oct. 1, 1959.

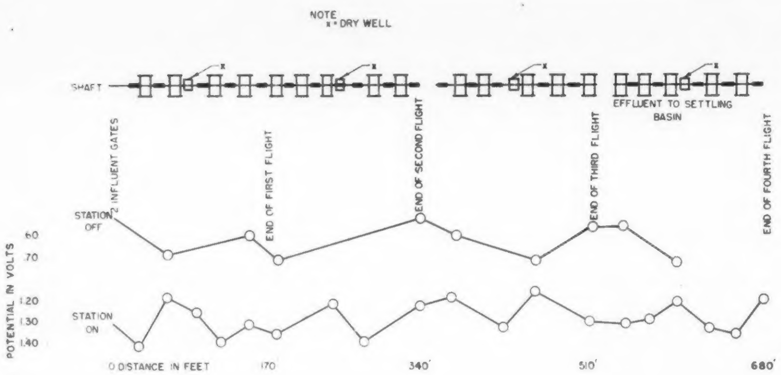


Figure 3—Potential of steel in mixing basin with respect to water. Note: Cathodic protection station operating 8.2 volts at 21.2 amperes. All readings negative to copper sulfate half cell.

tions were used with an average output per station of 18 amperes at 8 volts.

Two inch x 72 inch graphite anodes were mounted as shown in Figure 2. The anodes, 248 of them, were anchored to the concrete walls by means of 4 x 4 redwood supports. The redwood was notched to allow the anodes to fit between the wood and the concrete wall. The figure shows a close up of two adjacent anodes and two of the connections.

Tests made during the first year of operation indicated that the steel in the mixing basins and the drives in the settling basins were satisfactorily protected, but the moving chains were not adequately protected.

Officials of other filtration plants had concluded that it was more economical to recoat the moving chains than to install magnesium anodes.

At this point an economic study indicated that the yearly cost of coating the 13,200 lineal feet of chain would be $1,800.00. The total cost of installing one 1.3 inch diameter x 4 feet, magnesium anode on each of the 660 redwood scrapers was estimated to be $4,600.00. With a three year life expectancy this would give a yearly cost of just over $1,500.00. Larger anodes or multiples of the 1.3 inch rods would spiral the cost upward.

Analysis of the test data showed that with rectifiers protecting the drives at the ends of each basin, only very little current was required to adequately increase the protection. Tests conducted over a one year period had indicated that one 1.3 inch x 4 foot rod would be sufficient to adequately increase this protection. Without resistors in the circuit, larger anodes or multiples of the 1.3 inch suffered accelerated attack and would not materially increase the life expectancy beyond three years.

Installation of resistors would pose a complicated insulation problem and offer greater possibilities of anode circuit failure. It was therefore decided to install a single rod without resistors.

Anode installation was both rapid and economical. Lead cables were attached on a production line basis by using center attachment points; it was necessary to drill and tap only once for each anode. Using this method the total length of wire required could be reduced and the connection would be at the point of minimum anode deterioration. By connecting to the center a single length of No. 12 TW wire could be used to form two lead wires. Again with proper precaution the bare wire and the machine screw head was fitted into a counter sunk hole. Then to form an insulated lead it was only necessary to fill the holes with resin.

At the job site the anodes were centered on each individual scraper and secured by means of three single hole cast steel 1 inch pipe straps. One pipe strap was placed 4 inches from each anode end. As an added protection the wire connection was taped. The third strap was secured directly over the wire-anode connection.

The electrical circuit was then completed by connecting one of the anode lead wires underneath one of the bolts holding the scraper to each of the chains forming the pairs.

Routine Operating Tests

Routine semi-yearly operating potential surveys have been made since protection was installed. At first it was believed necessary to contact the steel shaft with a probe connected to a pole on which a copper sulfate electrode had been mounted. Accurate results were difficult to obtain and required a good deal of skill, both in contacting the shaft and interpreting the results. It was extremely difficult to contact a 5-inch shaft under eight feet of water. With poor probe contacts erroneous results would be obtained. Needless to say, such tests were time consuming.

At present, contacts are made to the shafts in both the mixing and settling basins through permanently anchored oil lines. The copper sulfate cell is attached to a pole or 1 inch plastic pipe and can readily be moved along the length of the shaft. If great accuracy is desired, the electrode is positioned three inches from the shaft. Readings taken with the electrode, within two feet of the shaft, will be fairly accurate and can be duplicated on the next series of readings. This position is the one most frequently used for testing.

Figure 3 shows a set of readings made over the drives in one mixing basin. The potentials are plotted as though the drives were continuous. Actually there were four separate drives. However, this system of plotting shows on one curve all values obtained. The minimum value obtained in this survey was one volt and the maximum was 1.46 volts. The upper curve shows station "off" readings and will assist in showing the amount of protection obtained.

The curves for the driveshafts in the settling basins are similar to those in the mixing basin. The drive chains in the settling basins are quite a different problem to test. Each chain is 660 lineal feet in length and there are a total of 20 chains in both basins. Each pair of chains carries redwood scrapers that push the sludge precipitated by the water treatment process into a disposal area. Two hours are required for a complete revolution.

Potential surveys are run over these chains once each year. The water is lowered in one basin at a time to a depth low enough to allow personnel to walk on the top deck, but high enough to cover the chains and anodes. It is a simple matter to use a probe and stab the chain at any desired location. In these tests the half cell is always positioned three inches above the chains.

Potential profile curves are obtained and indicate the minimum reading of about—0.85. The potential gradually increases as the chains come under the influence of the other magnesium anodes. An entire profile requires that the chain be turned twice and requires about eight hours test time per basin. This would be of little if any help in interpretation of results. Readings are usually taken on only the top deck and represent about ⅓ of each chain.

In addition to the semi-yearly surveys, plant maintenance men record the station output twice each month. These readings are inspected by the corrosion engineer and would indicate any necessity for corrosion control personnel to make additional tests or repairs.

Operating Experience

Experience gained over a six-year period indicates:

1. The cathodic protection has eliminated all corrosion.

2. The Scotch Fil and polyvinyl tape are excellent insulating materials. They are not as satisfactory as some of the thermal settling materials but much more economical. Their use will be continued.

3. The redwood supports are the source of greatest trouble. Each time a basin is emptied it is necessary to re-anchor one or two supports to the concrete, and the life of the graphite anodes has been very poor. Although the output per anode is only about half an ampere, approximately half of them are replaced each three years. The explanation for the poor life of the graphite could be the redwood anchors. With these anchors only about half the anode is exposed to the electrolyte. It is possible

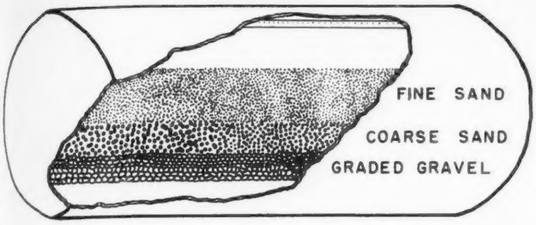


Figure 4—Horizontal type pressure filter.

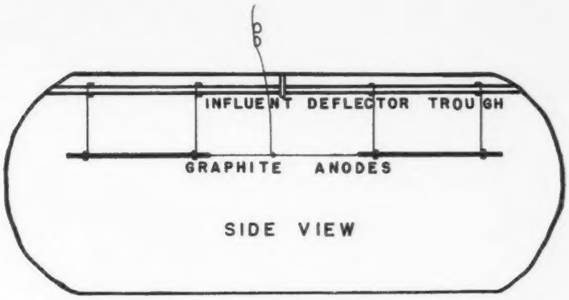


Figure 5—Anode mounting used for protection of Torrey Pines filter plant.

that all the current leaves the anode on the top half, thus allowing premature failures.

4. The 1.3 inch x 4 foot magnesium anodes connected to each flight will stop corrosion of the traveling chains; however, only a three year life can be expected. Using 17 lb. anodes or multiples of the 1.3 inch diameter anodes on each flight does not materially increase the life.

5. Spring contactors are not required to make cathode connections to the rotating drives. The connections can be made to the flange bolts and the bearings will make satisfactory contact to the drives.

6. The concrete reinforcing steel will receive some protection from the stations and in the case of the weirs, Figure 1 above, the potential of the steel is—0.85 volt or more.

Pressure Type Filters

History

For many years the City of San Diego Water Department used pressure type filters for water treatment. The department still operates two of these plants and acts as advisor to a department that operates a third.

Each filter consists of an 8 foot diameter by 20-foot long steel shell with an approximately 600 square foot surface area. The water enters through the top and passes through various grades of sand and gravel to collector pipes lying laterally to the main effluent line. When the filters become clogged with silt, they are backwashed by reversing the direction of water flow until the silt passes into a disposal line. Figure 4 shows a cutaway diagram of one filter.

Very early efforts by the department at corrosion prevention in these filters provide the author with much valuable information. These early attempts showed graphically some of the things that could not be accomplished. For example neither coal tar enamel nor vinyl paint could withstand the abrasion of the sand during backwashing the filters.

Impressed current cathodic protection systems were tried with the belief that flowing water would depolarize the steel. With that principle as a guide, a current density of 15 milliamperes per square foot was supplied. The net result was that the steel did not corrode, but calcium was precipitated from the water into the sand and gravel. After 6 months operation it was necessary to use pneumatic chisels to break up a solid concrete block that covered the entire lower half of 7 individual filters.

The Problem

The problem then was one of eliminating corrosion without causing calcium to precipitate in quantities that would seal the filter sand. It was necessary to accomplish this without the use of bituminous or paint coatings.

Preliminary Tests

Scale models were made of the filters and laboratory tests conducted to determine the potential at which the steel could be protected and still not precipitate calcium into the filter sand.

The actual operating conditions were simulated as nearly as possible. The water was circulated with a detention time of approximately 20 minutes. Actual filter sand was used.

The tests were started with the minimum potential of the steel with respect to a copper sulfate cell adjusted to—0.65 volts. This potential was 0.1 volt lower than with no protection and was maintained for two weeks. Measurements were made daily, and as was expected showed that corrosion occurred at several locations. The potential was dropped in 0.1 volt units and the tests repeated for two week periods until a potential of —3 volts was reached.

Under the conditions of these tests, corrosion ceased at a minimum potential of—1.1 volts with respect to a copper sulfate electrode. Calcium started to precipitate from the water at —1.8 volts.

Installation

Figure 5 shows the installation of anodes. Two 3 inch x 60 inch graphite anodes were used in each filter. The first installations were made with the two anodes lying on the filter sand without anchors. The installation proved unsatisfactory because the backwashing would float the anodes and cause them to move. They would either "short" against the shell or be near the shell, thus producing a potential which would precipitate calcium carbonate.

"Point" anodes consisting of ¼ inch x 1 inch lengths of platinum coated tantalum or groups of 1 inch by 12 inch silicon iron anodes mounted either perpendicularly or along the length of the shell were quickly eliminated because of the driving voltage required.

The final installations then were made as shown in the Figure 5. These arrangements have proven relatively successful.

Routine Tests

The standard potential profile readings as discussed elsewhere in this paper are taken twice yearly.

Several different methods of obtaining measurements have failed for one reason or the other. It is impossible to force a copper sulfate cell through the sand and gravel to obtain readings in the bottom of the filter.

An attempt was made to anchor rusty iron electrodes in the gravel so that measurements could be made to obtain a potential change. This failed because: (1) the gravel or backwashing forced the electrodes to move, and (2) backwashing would break the insulation if the wires were anchored, or bury the lead wires if not anchored.

At present 6 readings are obtained between a copper sulfate electrode and the filter shell. The readings are distributed around the filter shell and taken in the water above the sand. At best these readings are only an indication and do not represent actual operating conditions, because it is necessary to cease operations and open the filter.

The visual inspection made during each test is probably as helpful as the potential readings because it indicates a calcium buildup or corrosion at the top of each filter.

Operating Experience

Operating experience indicates the following:

1. Cathodic protection is the most desirable method of protecting the inside of pressure filters.

2. The known procedures for testing, available anodes, and methods for mounting anodes are only relatively satisfactory.

3. Overprotection can cause very rapid calcification of the filter gravel and in the waters from this area can completely "cement" the gravel to a point that pneumatic chisels are needed during repairs.

4. Where filters are operated in banks, variable resistors must be employed in

each filter circuit so that the desired potential can be obtained for each filter.

5. Anode Failures and experimental data indicate that minimum potentials of —0.85 volts can be obtained in one filter of a bank of several if that filter is connected to the cathode circuit but does not contain anodes. There is no explanation for these data. They do not agree with accepted theory, nor can the author explain them. This condition existed in two filters in a bank of 26 for a period of 3 months. After that time repairs were made and no further tests on that condition have been attempted.

Summary and Conclusions

The moving drives and chains in the chemical mixing and settling basins of rapid sand filtration plants can be adequately cathodically protected. This method of protection is more economical and easier to maintain than adequate coatings.

Cathodic protection is believed to be the most satisfactory method for protecting pressure filters. However, better test methods and equipment are needed.

Acknowledgment

Particular thanks are due William Merrithew and representatives of the Metropolitan Water District's La Verne Filtration Plant, for the advice and help rendered during the design of protection at the Alvarado Filtration Plant.

Any discussion of this article not published above will appear in June, 1961 issue.

Technical Papers on Corrosion Welcomed

Authors of technical papers on corrosion are invited to submit them for review without invitation to the Editor of Corrosion. Write for "Guide for the Preparation and Presentation of Papers" sent free on request to prospective authors.

Zinc as a Self-Regulating Galvanic Anode For Ship Hulls*

By J. A. H. CARSON

Abstract

This report presents results of service trials of up to three years duration for high purity and alloyed zinc hull anodes. The trials demonstrated that zinc anodes of suitable composition are capable of providing complete cathodic protection for ship hulls for extended periods in sea water. The current output of alloyed anodes (0.3% aluminum or 0.1% aluminum + 0.05% cadmium) is reliable and predictable because these materials do not polarize with time.

Zinc hull anodes of suitable design can have useful current outputs for periods of eight to ten years in sea water. Bolting is a satisfactory method of fastening zinc anodes to a ship's hull. Zinc anodes cause little or no accelerated break-down of the adjacent hull paint.

The two outstanding advantages of the zinc anode systems namely, self-regulation and improved current distribution, are available at a competitive price. Compared to the cheapest of the controlled type systems, whether of the galvanic or impressed voltage type, the zinc anode system at 13 cents per sq. ft. per year costs: (a) slightly more for large wetted hull areas of around 50,000 sq. ft., (b) slightly less for hull areas of around 15,000 sq. ft. and (c) markedly less for smaller hull areas.

Recommendations are made for: (1) The more widespread use of zinc anodes for cathodic protection systems both on and in ships. (2) The use of high purity (ASTM Special High Grade) zinc alloyed with either aluminum, or aluminum plus cadmium, as the standard zinc anode material for all sea water applications. 5.2.2

About the Author

J. A. H. CARSON has been engaged in corrosion research for the Defense Research Board of Canada at its Pacific Naval Laboratory in HMC Dockyard, Esquimalt, British Columbia since graduation from University of British Columbia in 1950 (BASc in chemical engineering). He has specialized in marine corrosion, in particular marine cathodic protection. Mr. Carson is a member of NACE.

Advantages of Zinc Anode Systems

FOR NEARLY 150 years "zincs" have been used as galvanic anodes bolted or welded directly to ship hulls. During the last 10-15 years these zincs have begun to be replaced by controlled magnesium galvanic anodes and the many types of impressed current anodes. Notwithstanding the usefulness of these later anodes, the uncontroled galvanic zinc anodes possess two outstanding technical advantages, namely:

1. The anodes are self-regulating, which means that they can be fastened directly to the hull and thereafter require no attention.

2. Excellent current distribution can be obtained by locating anodes close to the various high cathode demand areas on the ship.

The good self-regulating feature of the current output of zinc anodes on a steel hull results from the ability of these anodes to:

(a) adjust their current output automatically to a wide range of current demands such as encountered on many RCN ships, and (b) automatically shut off the current before the "potential"* of the hull reaches the level where hydrogen gas is given off with subsequent damage to the hull paint. Both of these features are illustrated in Table 1 and are the direct result of the potential of zinc at 1.05 volts being conveniently below the 1.1-1.2 volt hydrogen evolution potential for steel, and at the same time being sufficiently above the 0.8 volt "protected" potential for a steel hull to provide practical current outputs.

Current distribution is, of course, dependent not on anode material but on the shape, arrangement and location of the anodes. The most effective current distribution is obtained when anodes are located near all the high demand areas so that there is full utilization of the higher current densities associated with proximity to the anodes. With the self-regulating type of galvanic anodes there is generally no problem in locating anodes close to the various areas of high current demand on the hull; (eg., the rudders, propellers and adjacent stern area, the amidships waterline area, main sea suctions and outlets, etc.) Locating the externally controlled type of anodes near all these areas would be both complex and costly.

Recent Developments On The Effect Of Composition On Zinc Anode Performance

In the past, "zincs" on ships sometimes failed because of poor installation procedures. More often however, the failure was due to the tendency of the impure zinc to stifle itself with dense adherent films of corrosion products. It was not uncommon on docking a ship to find a zinc unattacked, yet the steel stud and nut fastening it would be practically rusted away. The failure of zincs to provide lasting protection to the hulls of RCN ships was reported by Barnard.[1,2]

During the past 15 years a considerable amount of research has been directed towards the improvement of zinc anode performance by increasing anode purity and by alloying. The developments to-date are reviewed below.

In 1946 Clark[3] and Haas[4] found that iron over 0.01 percent caused anode stifling, that lead, tin and cadmium in amounts up to 1 percent had little effect, and that aluminum additions improved anode current output. May, Shuldiner and Burbank[5] recommended in 1948 that the iron content of the zinc used for galvanic anodes should be kept below 0.002 percent.

A further reduction to 0.0014 percent for the maximum concentration of iron was indicated by research sponsored by the American Zinc Institute at Harbour Island[7,8,9] and this limit was included in a U. S. Military Specification[6] for zinc anodes in April 1954. This indicated maximum was confirmed in April 1955 by Anderson and Teel,[10] who also found that with the addition of 0.11 percent aluminum, anodes containing as much as 0.033 percent iron maintained a current output equal to that from the unalloyed zinc with 0.0014 percent iron.

In Britain, Crennell and Wheeler[11] independently confirmed in October 1956 that the iron in zinc should be kept below a few parts per million and that additions of up to 1 percent aluminum counteracted the film forming effects of iron at as high a level as 0.02 percent.

That zinc anodes could provide long term protection to ship's hulls was demonstrated by Tytell and Preiser,[12] who in November 1956 reported that a high

TABLE 1—Current Output of Self-Regulating Zinc & Magnesium Anode Systems In Relation To Hull Potential

Hull Potential (Volts)	Driving EMF (Volts)		Hull Current Density* (MA/sq. Ft.)	
	Zinc	Magnesium	Zinc	Magnesium
1.05	0	0.5	0	3.3
1.00	0.05	0.55	1	3.7
0.90	0.15	0.65	3	4.3
0.80	0.25	0.75	5	5.0
0.70	0.35	0.85	7	5.7

*Anode systems designed to produce 5 milliamperes current per square foot of underwater hull at a hull potential of 0.80 volts.

★Submitted for publication October 13, 1959. This report also has appeared as Report 13, Defence Research Board, Pacific Naval Laboratory, Esquimalt, B. C., August, 1959.

*All potentials measured against and negative to a silver-silver chloride reference electrode.

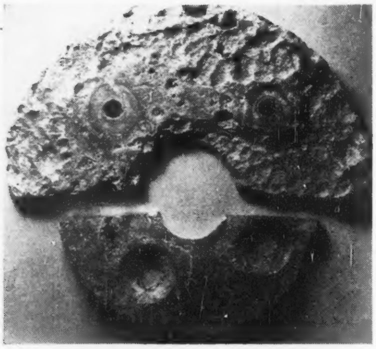
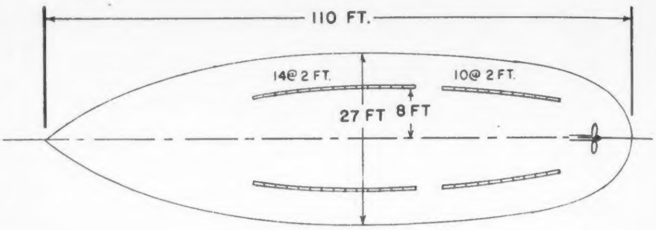


Figure 1—Active and inactive zincs from the same ship. The active anode at the top is No. 3 in Table 2; inactive anode on the bottom is No. 6.



UNDERWATER HULL AREA — — — — — — — — — — 3000 SQ. FT.
AREA OF BRONZE PROPELLOR — — — — — — — — 40 SQ. FT.
HULL PAINT SYSTEM — — — — — — — — — — — — VINYL
ANODE TYPE — — — — — — — — — — — — — — — — MK I-ASTM SPECIAL HIGH GRADE IA ZINC WITH IRON LESS THAN .0014%
TOTAL NO OF ANODES FITTED — — — — — — — — 48

Figure 2—Zinc anode arrangement on large tug.

purity-low iron zinc (99.99 percent zinc with iron less than .0014 percent) anode system had given complete protection to the hull of a tug for 16 months. In May 1959 they reported that this tug had been fully protected for an additional two years by the original anodes.[13]

In June 1957, Reichard and Lennox[14] reported that in ship and jetty tests, high purity zinc with the iron reduced to 0.0002 percent gave considerably higher current outputs than anodes containing the Military Specification MIL-A-18001 maximum of 0.0014 percent, but they also pointed out that it was difficult to keep the iron as low as 0.0002 percent in commercial anode production. They found that the addition of 0.1 percent aluminum plus 0.05 percent cadmium to ASTM Special High Grade zinc produced an anode with a consistently higher current output and smoother corrosion pattern than either the unalloyed high purity zinc with 0.0002 percent iron or the high purity zinc alloyed with single additions of 1.0 percent aluminum, 0.1 percent aluminum, or 0.05 percent cadmium.

PNL Investigations

At the Pacific Naval Laboratory interest in zinc as a galvanic anode was aroused in 1952 when three RCN ships fitted with the then standard "zincs," showed complete protection from corrosion for periods up to one year. Not all of the zincs had remained active (see Figure 1). Spectrographic analyses (see Table 2) indicated the possibility that the inactiviating effect was related to the iron content rather than to the overall purity.

At the time when it was becoming evident that the activity of zinc anodes was critically dependent on iron content, it was decided at PNL that service trials should be undertaken to confirm the reliability of the unalloyed high purity-low iron zinc. These trials were followed by a series of laboratory investigations[15] carried out jointly with the Research Division of the Consolidated Mining and Smelting Co. of Canada Ltd. In the laboratory, the superiority of the alloyed zinc was demonstrated and further service trials were undertaken with two of the most promising alloys. The results of all of the service trials form the main subject matter of this report.

Details of the high purity-low iron anode installations on the RCN tug and RCMP Patrol Vessel are shown in Figures 2 and 3. The anodes were designed at PNL.

Details of the alloyed zinc anode installation on the minesweeper are shown in Figures 4, 5 and 6. The flattened rectangular anode section and cast aluminum alloy inserts (the original PNL design had fabricated galvanized steel inserts) were modifications introduced by the Research Division of the Consolidated Mining and Smelting Co. of Canada. The rectangular anode section made casting easier. The cast aluminum insert was not only more economical but also avoided problems of anode distortion due to the unequal coefficients of expansion of anode and insert.

Results

High Purity-Low Iron Zinc Anodes On Large Tug

The "hull potential" record for this tug for the three year period ending in February 1959 is shown in Figure 7. During this time the tug was docked twice. It was "sandwashed" and repainted in February 1957 and sandblasted and repainted in June 1958.

The hull potential record had indicated complete protection during the period prior to February 1957 and the absence of corrosion was confirmed at that docking. In spite of the low potential periods encountered between the 1957 and 1958 drydockings, no corrosion was found in June 1958.

As shown by Figures 8 and 9 respectively, at both the 1957 and 1958 dockings the anode consumption was very non-uniform, ranging from 0 to 10 percent in 1957 and 2 to 30 percent in 1958. These figures also show the very uneven attack on individual anodes.

At both drydockings the anodes were completely covered with a layer of corrosion products. On the active areas of the anode this layer was soft and easily brushed off, but on the inactive areas it was hard and tenacious.

At the 1957 drydocking the port anodes were sandblasted, while on the starboard anodes the corrosion product films were left intact. This resulted in a markedly higher rate of consumption of the port anodes (by June 1958), namely 20-25 percent compared to the starboard average of 15-20 percent.

At the June 1958 docking a number of anodes were removed for a check on weight losses and iron content. These results are given in Table 3 and clearly show the inactivating effects of iron, even at concentrations below 0.0014 percent.

TABLE 2—Composition vs Activity of Ships' "Zincs"

Zinc No.	Activity of Zinc	Percent Chemically Determined		Percent Spectrographically Determined					Percent Purity
		Lead	Cadmium	Silicon	Manganese	Magnesium	Copper	Iron	
1	Active	0.28	0.032	ND*	ND	ND	≤.002	ND	99.6
2	Active	0.23	0.034	ND	ND	0.0005	0.001	ND	99.7
3	Active	0.27	0.032	ND	ND	ND	0.001	ND	99.6
4	Active	0.15	0.021	ND	ND	ND	0.001	ND	99.8
5	Active	0.13	0.023	ND	ND	ND	0.001	ND	99.8
6	Inactive	0.02	0.002	ND	ND	ND	0.001	0.02	99.9
7	Inactive	0.01	0.004	ND	0.0005	≤.005	≤.002	0.05	99.9

* ND—not detected.

TABLE 3—Weight Loss vs Iron Content Of High Purity Zinc Anodes From Large Tug

Anode No.	Wt. Loss In Lbs.	Wt. Loss In Percent of Orig. 48 Lbs.	Iron Content, Percent
7	14	29	0.0006
3	13	27	0.0003
6	10	21	0.0005
4	8	17	0.0006
8	6	13	0.0013
2	1	2	0.0023

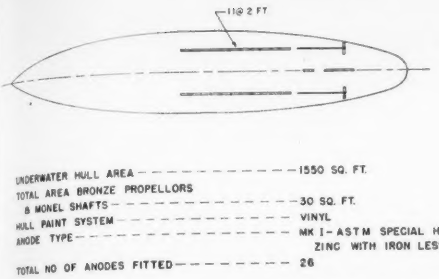

11@ 2 FT
UNDERWATER HULL AREA — — — — 1550 SQ. FT.
TOTAL AREA BRONZE PROPELLORS & MONEL SHAFTS — — — — 30 SQ. FT.
HULL PAINT SYSTEM — — — — VINYL
ANODE TYPE — — — — MK I - ASTM SPECIAL HIGH GRADE IA ZINC WITH IRON LESS THAN .0014 %
TOTAL NO OF ANODES FITTED — — — — 26

Figure 3—Zinc anode arrangement on RCMP patrol vessel.

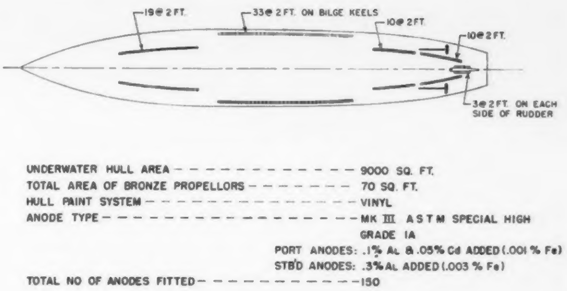

19@ 2 FT.
33@ 2 FT. ON BILGE KEELS
10@ 2 FT.
10@ 2 FT.
3@ 2 FT. ON EACH SIDE OF RUDDER
UNDERWATER HULL AREA — — — — 9000 SQ. FT.
TOTAL AREA OF BRONZE PROPELLORS — — — — 70 SQ. FT.
HULL PAINT SYSTEM — — — — VINYL
ANODE TYPE — — — — MK III ASTM SPECIAL HIGH GRADE IA
PORT ANODES: .1% AL & .05% Cd ADDED (.001 % Fe)
STB'D ANODES: .3% AL ADDED (.003 % Fe)
TOTAL NO OF ANODES FITTED — — — — 150

Figure 5—Zinc anode arrangement on minesweeper.

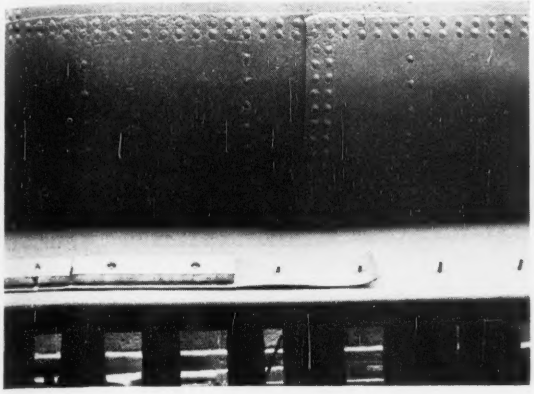


Figure 4—Method of mounting MK III zinc anode.

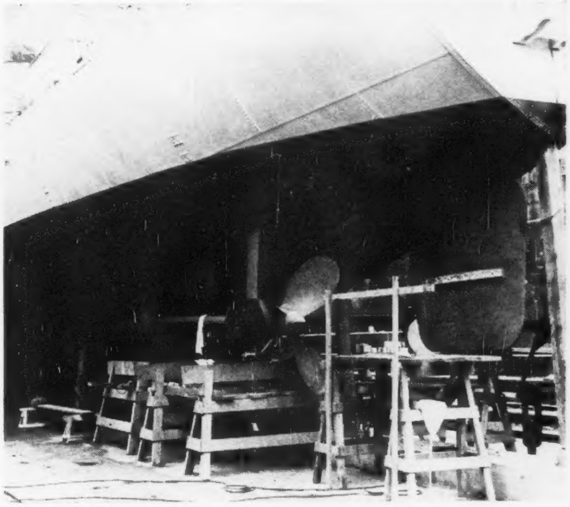


Figure 6—MK III anode system on stern of minesweeper.

High Purity-Low Iron Zinc Anodes On RCMP Patrol Vessel

Figure 10 shows the hull potential record for this vessel for the two year period ending in February 1959. During this period the vessel was docked twice. In January 1958 bare spots on the hull were "touched up" and in October of the same year the hull was "sandwashed" and repainted. The potential record indicates complete protection for the "at rest" and "underway" condition over most of this time. There were, unfortunately, some very long periods (up to 4 months) during which hull potentials were not obtained. These undocumented periods may have hidden lower potentials, since there was some corrosion at both the January and October 1958 dockings. This corrosion took the form of a light film of rust at some of the bare areas and pitting on the rudders, A-brackets and hull above the propellors. The maximum depth of this pitting at the October docking was around 0.02 inches, but there was no way of telling how much of this penetration had occurred since the anodes were fitted.

At the January docking the anodes were found to have been consumed most unevenly. By October, however, the anode surfaces had become much more even as shown in Figure 11. The consumption from anode to anode was quite uniform (with the exception of those at the stern) at around 10 percent for the 21 month period. The four stern anodes, being much closer to highly cathodic areas, and more widely separated, showed a consumption almost twice as great as the rest.

Just as on the tug, all anode surfaces showed corrosion product films.

Alloyed Zinc Anodes on Minesweeper

The hull potential record for this ship for the year ending in January 1959 is shown in Figure 12. As expected from the high readings there was no hull corrosion at the November 1958 docking. At that time the hull was "sandwashed" and repainted.

The consumption rate was quite uniform from anode to anode and about the same for both alloys (see Figure 13), being around 5 percent for all of the anodes with the exception of those at the stern. The stern anodes had lost about 7 percent of their weight in the nine month period. The active surfaces of the anodes were generally more evenly consumed than on the unalloyed anodes (compare Figure 13 with Figure 9), the 0.1 percent aluminum plus 0.05 cadmium alloy anodes showing the smoother surfaces of the two alloys. However, with both materials there was a pronounced tendency for only the top surface of the anode to corrode. This effect was most pronounced with the 0.3 percent aluminum alloy where the anode edges were

TABLE 4—Estimated Cathode Current Densities

Vessel	Period	Av. Anode Consumption Between Dry-Dockings (Percent)	Average Hull Potential (Volts)		Av. Est. Actual Cathode Current Density (MA/Sq. Ft.)		Ratio of Actual Current Output to Theoretical
			At Rest	Underway	At Rest	Underway	
TUG	Feb/56 to Feb/57	7	0.89	0.81	2.2	3.2	0.55
	Feb/57 to June/58	13	0.84	0.72	3.0	4.7	0.60
PATROL VESSEL	Jan/57 to Jan/58	6	0.95	0.85	1.8	3.7	0.70
	Jan/58 to Oct/58	5	0.92	0.79	2.0	4.1	0.65
MINE-SWEEPER	Feb/58 to Nov/58	5.5	0.98	0.88	1.6	3.8	0.90

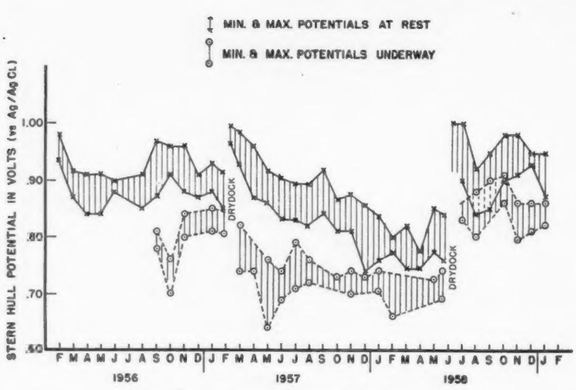


Figure 7—Hull potential record for large tug.

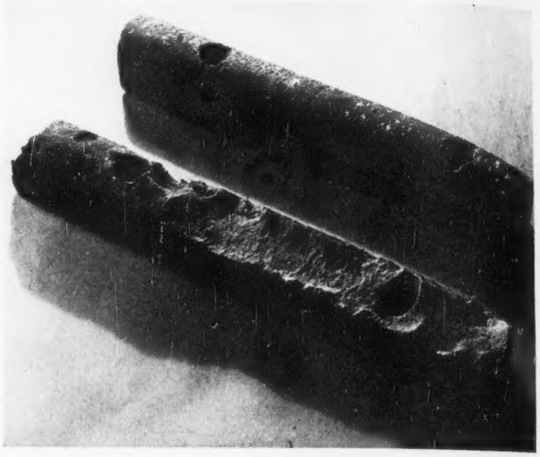


Figure 9—Non-uniform consumption of the MK I high purity-low iron zinc anodes after two years on the tug. Note uneven attack on individual anodes. The upper anode is No. 2 and the lower anode No. 6 in Table 3. Slices have been taken from the ends of the anodes for analytical purposes.

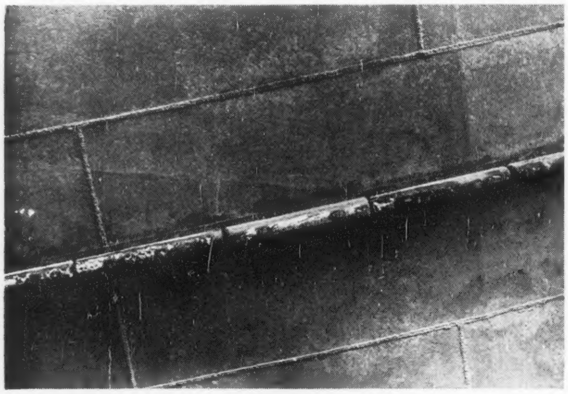


Figure 8—Non-uniform consumption of MK I high purity-low iron zinc anodes after one year on tug. The anode in center of picture was practically unconsumed. Note also the uneven attack of individual anodes.

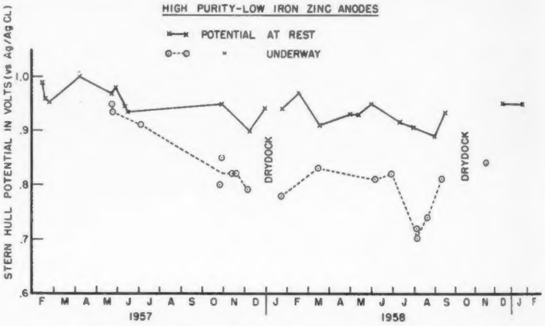


Figure 10—Hull potential record for RCMP patrol vessel.

actually sharp. There was a good indication that this preferential attack was partly due to paint "overspray" on the sides of the anodes but this paint could not account for the total effect. The cause of the preferential top surface attack is being investigated further.

Both alloys showed thin soft corrosion product films on the active surfaces.

Discussion

The principal object of these trials was to confirm that zinc anode systems are practical for the cathodic protection of ship hulls. The evaluation of the performance of the anode systems was based on:

1. The ability of the anodes to reach and maintain their design current output.

2. The suitability of the anode geometry, arrangement and method of fastening.

3. The avoidance of unwanted secondary effects such as excessive stripping of paints near the anodes.

4. The cost in comparison to other types of cathodic protection systems.

Current Output

Table 4 gives actual cathode current densities estimated from anode weight losses and average "hull potentials." The estimates take into consideration the proportion of time for the "underway" and "at rest" conditions. Anode efficiency was taken as 95 percent.[15] Theoretical current outputs were based on the measured average hull potentials and calculated sea path resistances.

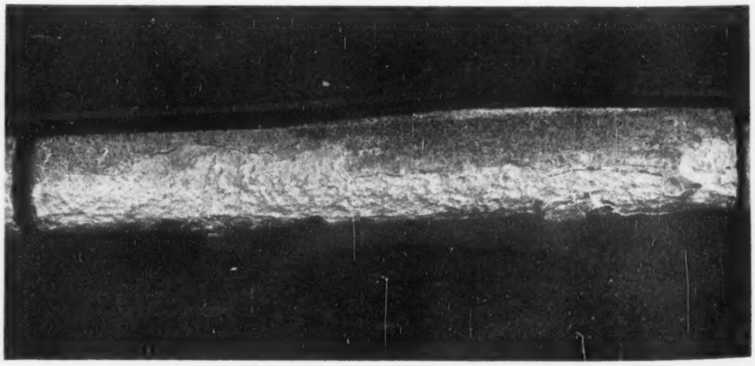


Figure 11—More even consumption of MK I high purity-low iron zinc anode after 20 months on patrol vessel.

Note the low ratio of actual to theoretical current output for the unalloyed high purity-low iron anodes on the tug and the patrol vessel. That the anode output was reduced primarily by the polarizing effect of the corrosion product layer was supported by the following data:

1. This material showed a significant increase in anode polarization (70 millivolts) in two months at similar current densities in laboratory trials[15] and continued to polarize at a reducing rate thereafter.

2. The removal by sandblasting of the corrosion product layer from the port anodes, enabled them to put out, in the succeeding 16 months, almost 50 percent

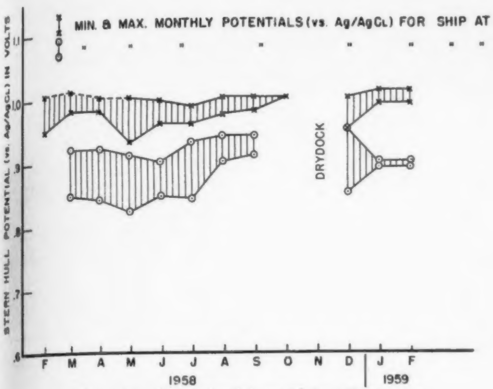


Figure 12—Hull potential record for minesweeper.

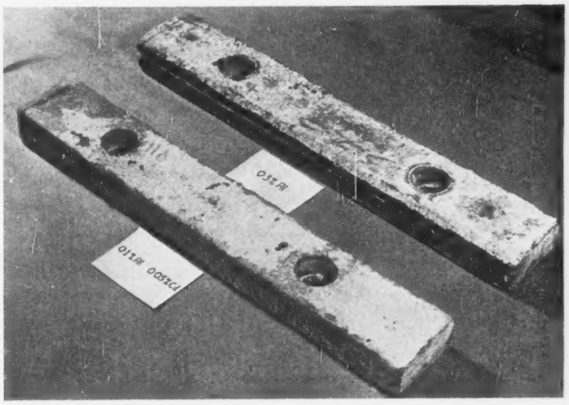


Figure 13—Alloyed zinc anodes after 15 months on minesweeper. Note that the anode consumption is more even than that shown in Figures 9 and 11. Also note the non-rounded edges on the anodes.

more current than the uncleaned starboard anodes.

In comparison, the alloyed anodes on the minesweeper produced an estimated 90 percent of their theoretical output. The slight reduction from the theoretical output in this case can be attributed to the reduced active surface area where only the top surface of the anode was producing current. Further data supporting the conclusion that there was no increase in anode polarization with the alloyed materials was:

1. These same materials showed a negligible increase in anode polarization in several months at similar anode current densities in laboratory tests.[15]

2. There was practically no reduction in the potential of the minesweeper during a full year's operation. There are other possible explanations for this steady potential but the most probable one is that the anodes did not polarize and at the same time the current requirements did not increase. The latter part of this conclusion was given support by the observation that the amount of paint stripping at the November, 1958 drydocking was quite minor.

This freedom from increasing anode polarization means that the current output of the alloyed anodes can be reliably predicted at any time.

Anode Shape, Arrangement and Method of Attachment

The shape of the anodes, the method of arranging them on the hull and the method of attachment were chosen for:

1. Maximum current output consistent with long anode life. (long anode life to reduce labor costs and make the useful life of the anodes relatively independent of drydocking schedules).

2. Maximum simplicity of installation and replacement.

To get a long anode life the anode sections were made 2 inches (or more) thick. Since current output is directly proportional to length but proportional to the logarithm of the characteristic anode section, maximum current output consistent with long anode life was obtained by making the anodes long compared to their section dimensions. Because of the overriding effect of length, long anodes (or anode arrays) show the least difference in current output between the new and the used conditions.

With regard to the method of fastening the anodes, the reason most often given for the use of weld-on type zinc anodes is that the welding guarantees a good metallic connection. This is true, but in the author's experience, both in these trials and from observations of the bolt-on plate type "zincs" used in the past, bolted fastenings provide adequate metallic contact, particularly where the anode is secured by means of an integral insert of a less active metal.

The bolt-on anodes have the following advantages over the weld-on type:

1. Re-installation costs are lower.

2. Repeated damage to the hull plating and to the paint at the points of weld attachment is avoided.

3. Gas freeing of adjacent storage spaces is not needed other than at the initial installation of the anode securing studs.

Effect On Hull Paint

A vinyl type hull paint system was used on all these trial vessels. With the exception of the minesweeper, there was not, at any of the five drydockings involved, any evidence of accelerated paint blistering or stripping near the anodes; the area where the highest hull potentials would be encountered. On the minesweeper, however, there was a definite tendency towards increased blistering in the vicinity of the anodes. It is possible that the increased blister incidence resulted from the higher cathode current densities corresponding to the consistently higher hull potentials on this ship. More likely, however, it was due to the paint being very thin (around 0.003 inch thick) in this region. The general conclusion was, therefore, that the vinyl paints are not significantly affected by the uncontrolled zinc anodes.

Cost

On the basis of a 20-year period, the cost of a zinc anode system of the type used in these trials has been estimated[16] at about 13 cents/sq.ft. of wetted hull/yr. For ships of destroyer escort size (wetted hull area approximately 15,000 sq. ft.) this is slightly less than the cost of the cheapest of the other types of galvanic or impressed voltage anode systems presently available. For larger hull areas (e.g., 50,000 sq. ft.) some of the impressed voltage systems are cheaper (e.g., a lead-2 percent silver anode system is about 11.5 cents/sq.ft./yr.). However, for smaller hulls, the zinc anode system is the cheapest by a wide margin (e.g., the cost for a 1,500 sq. ft. wetted hull area at 13 cents/sq.ft./yr. is one third that of the cheapest controlled type system).

The simplicity of the self-regulated zinc anode systems, their inherent capability of providing excellent current distribution, their demonstrated reliability, and finally, their competitive cost position, make them the logical anode choice for smaller ships and a strong contender for top place amongst the protection systems for the larger ship hulls.

Recommendations

It is recommended that:

1. Consideration be given to the more widespread use of the self-regulating, uniform current distribution features of zinc anodes for cathodic protection systems both on and in ships.

2. High purity (ASTM Special High Grade) zinc alloyed with either aluminum, or aluminum plus cadmium, be made the standard zinc anode material for all sea water applications.

Acknowledgments

The author is indebted to many personnel, past and present, of the Royal Canadian Navy, the RCMP Marine Division and the Research and Development Division of the Consolidated Mining and Smelting Co. of Canada Ltd. for their ready assistance in making these trials possible.

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Any discussion of this article not published above will appear in June, 1961 issue.

Chromium Electroplates for Corrosion Protection Of Stressed AISI 410 Steel In High Temperature, High Purity Water*

By HENRY SUSS

Abstract

The use of chromium plates for protection of AISI 410 steel against stress corrosion cracking gave anomalous results. The coating either offered protection under conditions which produced failure in unplated material, or caused accelerated failures under conditions which did not cause unplated material to fail. Factors which may have contributed to the anomalous results are discussed. Introduction of oxygen into 300 F-water systems caused accelerated stress-corrosion failures, especially for the chromium-plated samples, with applied stresses as low as 60,000 psi. From information presently available the use of chromium deposits is not recommended for corrosion protection of AISI 410 steel materials that are susceptible to stress corrosion and/or intergranular attack.

AISI 410 steel tempered at 1125 F minimum, not susceptible to stress corrosion failure, indicated insignificant or no pitting attack after 6 weeks exposure in air-saturated water at 300 F. There are no significant advantages in the use of chromium plate to reduce general corrosion attack. There is a possibility that this coating, under certain conditions of application, may promote accelerated pitting attack. Cobalt-base alloys, such as Stellite 6, in contact with chromium-plated AISI 410 steel, tempered at 1125 F minimum, will promote accelerated dissolution of the chromium plate adjacent to juncture between Stellite 6 and chromium plate, and pitting of base metal in these areas. No attack of chromium plate in the crevice was noted, but accelerated attack of the base metal through the cracks in the chromium plate was noted in these areas.

5.3.2

Introduction

AISI 410 steel (low carbon—12 percent chromium steel) preferably at high hardness (RC 36-42, tempered at 650 F), was a material of extreme interest for use in high temperature, high purity waters. Its main disadvantage was its known susceptibility to stress corrosion cracking.[1] To eliminate this problem, AISI 410 steel tempered at 1125 F minimum, to RC hardness of 20-30, was considered as a possible alternate material. Objections to the softer material were its higher general corrosion rates and its possible susceptibility to pitting in oxygenated waters. Therefore, a program was initiated to evaluate the use of chromium plate for corrosion protection of AISI 410 steel in both conditions (650 and 1125 F tempers). Chromium plate has been commonly considered one of the better metallic coatings for corrosion protection under the specific service conditions anticipated.

Protection of AISI 410 Steel Tempered at 650 F to RC 36-42⁽¹⁾

The test work was performed at Knolls Atomic Power Laboratory by Galonian and co-workers[2] and at Bettis Atomic Power Laboratory by Eric Rau and co-workers.[3, 4, 5] The KAPL test specimen was a 4-point bent beam specimen exposed with applied stresses of 40,000, 45,000, 60,000, and 75,000 psi for bare samples, and applied stress of 75,000 psi only for the chromium-plated samples. Test specimens were exposed in holders as shown in Figure 1. All samples were exposed in static autoclaves to either high-purity hydrogen ammoniated water of pH 8.5 to 9.5 (see Table 1) or high-purity, air-saturated water at 300 F. No chemical controls were maintained during the actual exposure cycle. The chemistry of the hydrogen-ammonium water did not change during the test. The variations with time of pH, conductivity, and oxygen content in air-saturated water for two exposure periods are shown in Figures 2 and 3, respectively. The BAPL tests for the same material were based on a 3-point bent beam specimen with applied stresses of 40,000, 60,000, and 80,000 psi. Samples were exposed in circulating autoclaves in hydrogen-ammoniated water, hydrogen-lithium hydroxide water, and water with varying oxygen content (0.5 to 40 ppm). The autoclaves were operated at both 300 and 600 F under controlled water chemistry. These tests were supplemented by exposure of miniature pressure tubes at 300 F only. The tubes were machined to a wall thickness which would, under test system pressure, cause them to be subjected to the desired applied stress, usually at 60,000 psi.

About the Author

HENRY SUSS is a material engineer at General Electric's Knolls Atomic Power Laboratory, Schenectady, N. Y. He has a BS from New York University and an MA from Columbia University. He has been in corrosion work for 12 years.

The results at KAPL and BAPL showed that with bare AISI 410 steel, failures occured within 2 to 8 weeks in 300F air-saturated water, at the lowest applied stress levels of 40,000 psi. In low oxygen (0.5 to 2 ppm)water, there was a marked increase in susceptibility to pitting and stress corrosion at stress levels as low as 60,000 psi. No specimen failures were experienced in hydrogen-ammoniated or lithium-hydroxide water in 6 months, with applied stresses as high as 80,000 psi.

Both KAPL and BAPL test data revealed anomalous results with chromium deposits. When oxygen was introduced into the system (300F), accelerated failure of many chromium-plated beam and pressurized tubes (applied stress about 60,000 psi) occurred, or a more rapid propagation of cracks resulted. These data emphasized the importance of keeping oxygen levels below 0.1 ppm in a high-purity water system. In addition, on exposure in air-saturated water at 300F, samples plated with a chromium deposit (0.0005-in. nominal thickness) to same specification⁽²⁾ but applied by two different sources showed failures in less than 1

TABLE 1—Water Chemistry

Condition	
Water Before Additions	pH 6.5 – 7.5 Resistivity 1 – 2 megohm-cm
Test Conditions	Temperature – 300F Pressure – Saturation
Hydrogen-Ammonia	pH – 8.5 – 9.5 Ammonia – 0.3 – 0.7 ppm Hydrogen – 30 – 60 cc/kg H_2O Oxygen – less than 0.1 ppm Resistivity – 250,000 to 500,000 ohm-cm
Hydrogen-LiOH	pH – 10 – 11 LiOH – 2.4 – 24 ppm Hydrogen – 30 – 60 cc/kg H_2O Oxygen – less than 0.1 ppm Resistivity – 20,000 ohm-cm
Low Oxygen	Additions made to ammoniated or LiOH water to give oxygen content of 0.5 – 2.0 ppm Resistivity – not reported

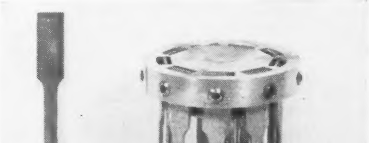


Figure 1—Stress corrosion specimen and fixture used for stressing specimens.

★Submitted for publication October 2, 1959. A paper presented at a meeting of the Northeast Region, National Association of Corrosion Engineers, Baltimore, Maryland, October 5-8, 1959.

⁽¹⁾ The results reported in this section are very similar to data reported in Reference 1 and presented at the 15th Annual Conference, National Association of Corrosion Engineers, Chicago, Illinois, March, 1959.

⁽²⁾ BAPL Specification - 12156E—A modification of ASTM Specification B177. Used the standard 33-oz. Cr_2O_3—0.33-oz. sulfuric acid/gallon of water. Temperature of bath, 130 F; current density 300 amps/sq. ft. (asf).

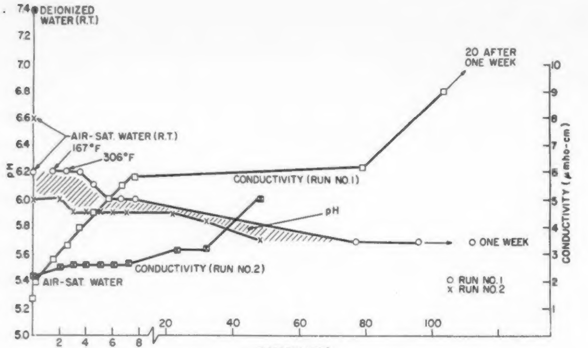


Figure 2—pH and conductivity change in 300 F air-saturated water contained in static autoclave (preliminary).

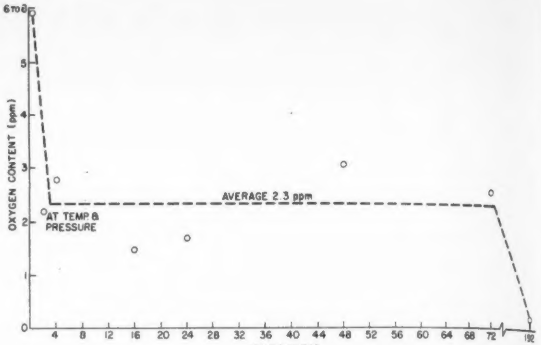


Figure 3—Changes in oxygen content in air-saturated water static autoclaves 300 F (preliminary).

Figure 4—As polished, 500X. Source A chromium plate on AISI 410, RC36-42—as plated.

Figure 5—As polished. 500X. Source B chromium plate on AISI 410, RC36-42—as plated.

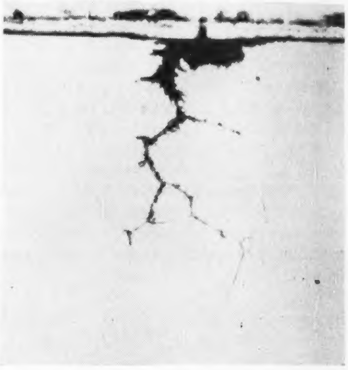


Figure 6—As polished, 500 X. Source A chromium plate on AISI 410, RC36-42 after 1 week air saturated water 300F—applied stress 75,000 psi. Specimen failed.

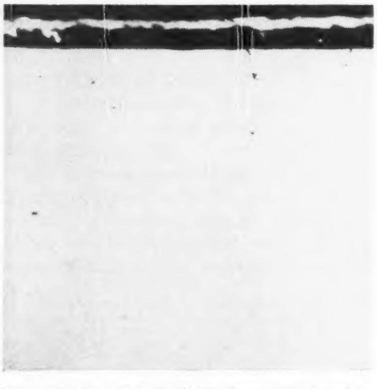
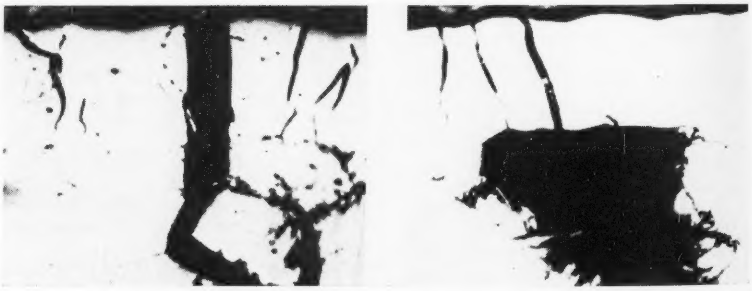


Figure 7—As polished, 500X. Source B chromium plate on AISI 410, RC36-42 after 8 weeks exposure air saturated water 300F—applied stress 75,000 psi. No cracks in base metal.



A—Crack in base metal started intergranularly.

B—Failure in base metal started as pit, then crack propagated intergranularly.

Figure 8—As polished, 1000X Typical cracks in same chromium plate deposit on AISI 410 RC36-42 after 1 week exposure 300 F air saturated water—applied stress 75,000 psi. Specimen failed.

week (source A) and no failures after 8 weeks (source B).

Typical microphotographs of the as-received and as-exposed chromium-plated samples are shown in Figures 4 through 7. The bulk of the chomium deposit in both samples, as-received (Figures 4 and 5), appeared to be "crack-free." Both samples revealed some discontinuities, but the "poorer" quality deposit (source A) showed cracks of a greater number and width. As a result of the exposure, this latter deposit developed a considerable number of additional cracks across the entire stressed area (Figure 6).

More typical areas are shown in Figure 8. The cracking of the deposit and corollary exposure of the base metal caused accelerated pitting and/or promoted crack propagation into the base metal. These cracks in the deposit and attack on the base metal are typical of all chromium plates that provided no protection or caused accelerated failures. The "better" quality specimens (source B) did not reveal any significant increase in the amount or extent of the cracks, nor produced any marked accelerated attack on the base metal as a result of a similar exposure (Figure 7). These two sets of samples had been plated to produce a chromium plate thickness of 0.0003 to 0.0005 in. The resultant samples actually had thicknesses of 0.0004 in. (source B) and 0.0015 in. (source A). As plating time was held constant, it is apparent that the current density was not properly controlled.

The corrosion test results revealed that the thicker coating deposited at the greater rate per unit time was more brittle and had a greater number of discontinuities, which made chromium plate more prone to failure under conditions of the test. This could be an instance in which improper control of current density leads to premature failure.

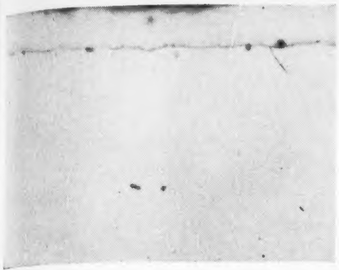


Figure 9—As polished, 500X. Source A 130F, 3 amp/ft²—chromium plate 0.5 mil nominal on AISI 410, 1125F temper—as plated.

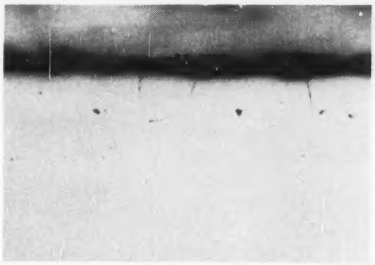


Figure 10—As polished, 500X. Source B 130F, 300 amp/ft² chromium plate 0.5 mil nominal on AISI 410, 1125F temper—as plated.

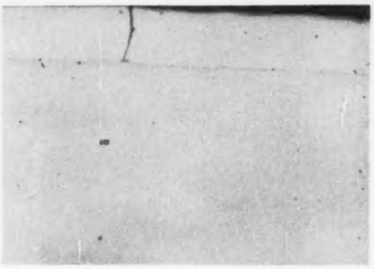


Figure 11—As polished, 500X. Source C 130F, 300 amp/ft² chromium plate 0.5 mil nominal on AISI 410, 1125F temper—as plated.

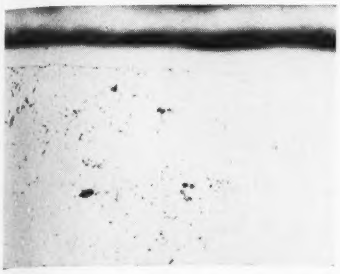


Figure 12—As polished, 500X. Source D (proprietary) chromium plate 0.2 - 0.5 mils on AISI 410, 1125F temper—as plated.

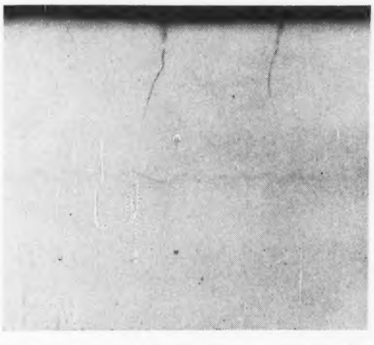


Figure 13—As polished, 500X. Source A 130F, 300 amp/ft² chromium plate 2.0 mils nominal on AISI 410, 1125F temper—as plated.

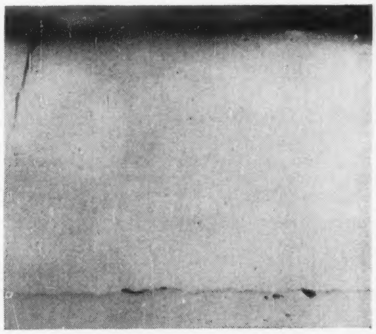


Figure 14—As polished, 750X. Source B 130F, 300 amp/ft² chromium plate 2.0 mils nominal on AISI 410, 1125F temper—as plated.

Figure 15—As polished, 750X. Source C 130F, 300 amp/ft² chromium plate 2.0 mils nominal on AISI 410, 1125F temper—as plated.

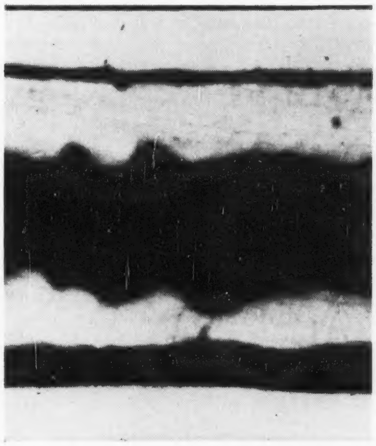


Figure 16—As polished, 500X. Source C 160F, 300 amp/ft² chromium plate 0.5 mils nominal on AISI 410, 1125F temper—as plated.

Figure 17—As polished, 500X. Source C 160F, 300 amp/ft² chromium plate 2.0 mils nominal on AISI 410, 1125F temper—as plated.

Tests at BAPL were based on the exposure of 0.0005-in. chromium deposits plated by 3 to 4 different sources to the requirements of the same specifications previously referenced. Some failures of chromium-plated specimens with applied stresses of 60,000 and 80,000 psi on exposure to hydrogen-ammoniated water (pH 8.5 to 9.5) at 300 F were evident. (Typical failures were similar to that shown in Figure 8.) There were no failures of unplated material under similar conditions of exposure (applied stresses up to 80,000 psi) or chromium-plated samples (applied stress of 40,000 psi) under similar conditions of exposure. Also there were no failures (applied stresses of 80,000 psi) of any chromium-plated samples in hydrogen-LiOH water (pH 11) at 300 F.

A possible explanation for these anomalous results follows. Chromium deposits contain discontinuities, usually cracks, attributed to their high tensile stresses and to operating conditions of the plating process. As plating continues, these discontinuities are usually covered. New cracks which develop as plating thickness increases usually do not extend to the base metal.

Plating solution could readily be entrapped in sub-surface discontinuities. Cohen[6] in work on chromium electroplating reported: "A film-like network of a compound of chromium existed within the several electrochromium deposits which were examined. This network was associated with the usual crack system observed in chromium electroplates. The film isolated from a heated chromium plate was found to consit of Cr_2O_3 and was about 0.05 percent by weight of the deposit."

Tests at KAPL have indicated that Cr_2O_3 is partially soluble by exposure at 212 F to ammoniated water, pH 8.8, and forms a collodial precipitate with LiOH water, pH 10.5 to 11. It is very probable that the application of the applied stress caused the discontinuities in the deposit to open and expose the base metal. The entrapped Cr_2O_3 reacted with ammonia to produce a conductive solution in localized areas which caused accelerated (galvanic) corrosion with resultant stress-corrosion failure of the base metal. As LiOH forms an insoluble precipitate with Cr_2O_3, a similar phenomenon did not occur in the higher pH water. This theory is substantiated further by the following facts:

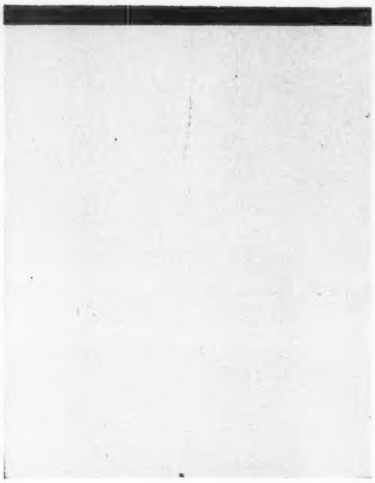


Figure 18—As polished, 500X. Opposite side to sample shown in Figure 17. Plate two times as thick.

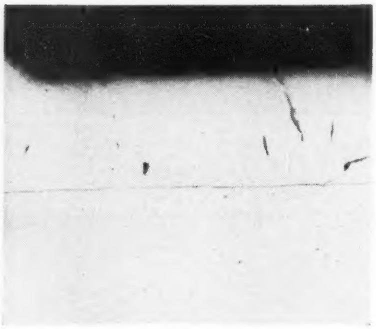


Figure 19—As polished, 500X. Source C 130F, 900 amp/ft² chromium plate on AISI 410, 1125F temper—as plated.

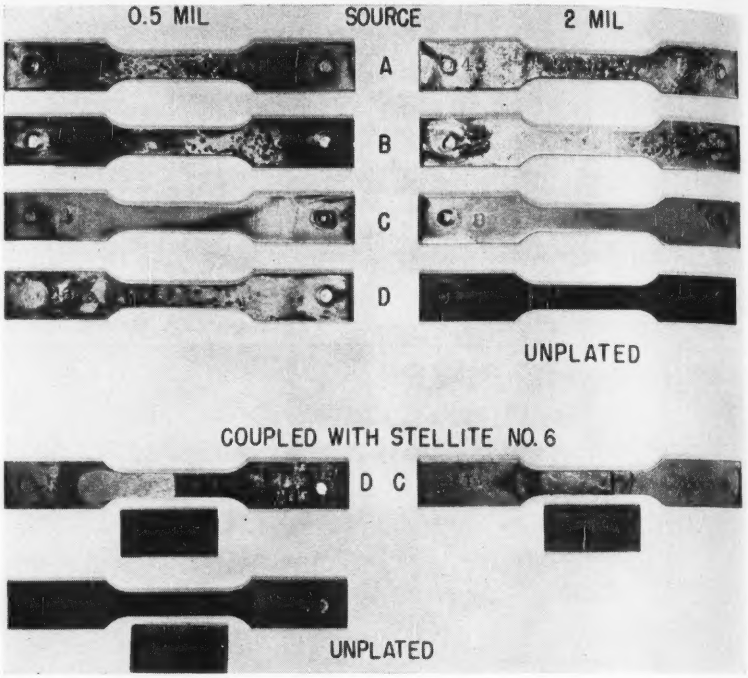


Figure 20—Post test appearance of chromium plated T-410 steel. Stress corrosion samples were tested six weeks in 300 F air-saturated water. Plated at 130 F, standard bath, 300 amp/ft².

1. AISI 410 steel (RC 36-42) shows very low corrosion rates in hydrogen-ammoniated water at 300 F.[2]

2. The conductivity (resistivity-200,000 to 500,000 ohm-cm) of the normal ammoniated solution is too low to promote, by itself, galvanic action.

3. Some factors must have been present which promoted either localized or galvanic action, since excessive pitting was evident beneath each "through-crack" in the chromium plate of all the specimens which failed.

Chromium plated specimens (same plating sources and plated at the same time) which caused accelerated failure at 300F in hydrogen-ammoniated water did not reveal any failures on exposures (at BAPL) to the same environment at 600 F.[5] Unfortunately, these specimens were not available for further studies.

Protection of AISI 410 Steel Tempered At 1125F Minimum

The test specimens were plated to two different nominal thicknesses, 0.5 and 2.0 mils, by three different sources, A, B, and C, to the requirements of the same specifications referenced above; these plates will be referred to as standard deposits. A second set was plated by source C to the same requirements except bath temperature was maintained at 160F. These latter deposits were to be "crack-free." A third set was plated at 130F at current density 2½ to 3 times greater than that specified in order to study the effects on the resultant deposit.

Samples of a proprietary (source D) chromium-rich deposit (Electrolizing) were included in the test program. The test specimens were exposed in the same holder as shown in Figure 1 with an applied stress of 60,000 psi in air-saturated water at 300F in static autoclaves. Water chemistry conditions were similar to those shown in Figures 2 and 3. Included in the test program were specimens, in triplicate, of all conditions of chromium plating. Unplated samples were used as controls. Also used were samples plated by source C, 130 and 160F, 2 mils, source D, and unplated in contact with Stellite 6 (cobalt-base alloy).

Typical microphotographs of the standard 0.0005-in. deposits, as supplied by the three different electroplaters, are shown in Figures 9 through 11. Figure 12 reveals the typical structure of source D deposit. A wide variation in nature and extent of cracks is evident. The proprietary coating (source D) indicated porosity (no cracks) which is not evident in the microphotograph. The structure of the standard 0.002-in. deposits from the three different sources is shown in Figures 13 through 15. These indicated slight but not significant differences in degree or extent of cracking. These cracks did not show any "through-porosity": cracks extending from outside surface to the base metal.

Figure 16, 2 different surfaces 0.5 mils, and Figure 17, 2.0 mils, show the crack-free nature of the deposits plated at 160F. The opposite face of the same specimen (Figure 17) is shown in Figure 18. This face was apparently plated to about twice the specified thickness and showed numerous scattered cracks. Since the plating time had been constant, the thicker layer had been deposited at a much greater rate because of the higher current density. The deposit, deliberately plated at 2½ to 3 times greater rate, showed the structure as seen in Figure 19. This coating revealed the greatest degree of cracking and nonuniformity in thickness. The structures illustrated in Figures 18 and 19 emphasize the importance of proper control of current density to ensure uniformly high quality of chromium electroplates.

The appearance of various specimens after removal from 6-weeks exposure are shown in Figure 20. Wide variations in extent of attack are evident. These are reviewed later in this report. Duplicate specimens of each variation exposed to test (4 to 6 weeks) were studied metallographically. The results are summarized as follows:

As results of the test conditions, all chromium deposits (including the crack-free) cracked or showed increased extent of cracking with a resultant exposure of the base metal. The chromium plates per se were corrosion-resistant. The apparent failure of the plate was caused by accelerated attack (pitting) of the base metal through the cracks with resultant undercutting and/or failure of the bond. The extent of the attack was not time-dependent to a significant degree, but did appear to depend mainly on the number, size, and location of cracks in the chro-

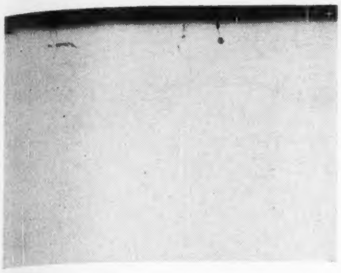


Figure 21—As polished, 250X. Typical of Source A & B 130F chromium plate 0.5 mils nominal after 6 weeks exposure 300F air saturated water—60,000 psi applied stress.

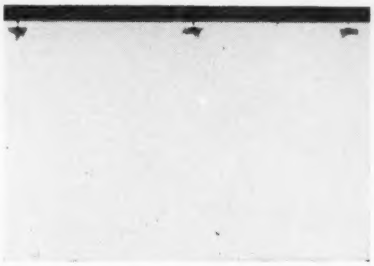


Figure 22—As polished, 250X. Source C 130F, 300 amp/ft^2 chromium plate 0.5 mils nominal after 6 weeks exposure 300F air saturated water—60,000 psi applied stress.

Figure 23—As polished, 250X. Typical Source C 160F—300 amp/ft^2 chromium plate 0.5 mils nominal after 4 weeks exposure 300F air saturated water—60,000 psi applied stress.

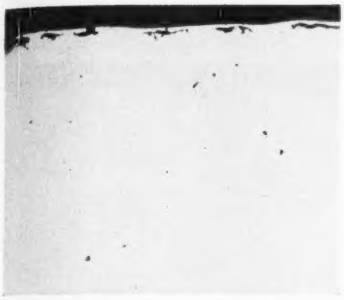


Figure 24—As polished, 250X. Source D (proprietary) chromium plate 0.2-0.5 mils nominal after 6 weeks exposure 300F air saturated water—60,000 psi applied stress.

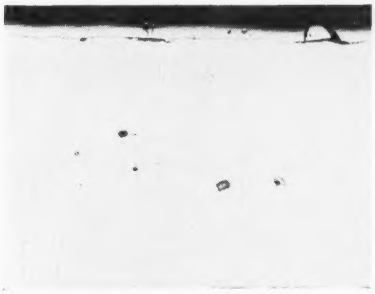


Figure 25—As polished, 250X. Source D (proprietary) chromium plate 0.2-0.5 mils nominal after 6 weeks exposure 300F air saturated water—60,000 psi applied stress.

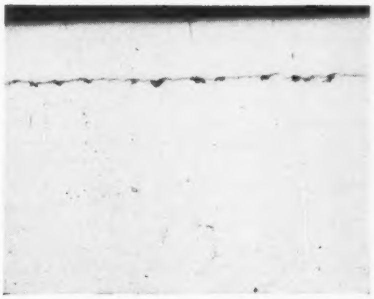


Figure 26—As polished, 250X. Typical source A & B 130F chromium plate 2.0 mils nominal after 6 weeks exposure 300F air saturated water—60,000 psi applied stress.

Figure 27—As polished, 250X. Typical source C 130F and 160F chromium plate 2.0 mils nominal after 6 weeks exposure 300F air saturated water—60,000 psi applied stress.

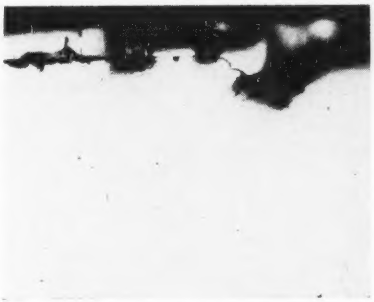


Figure 28—As polished, 250X. Typical for chromium plate deliberately plated at a higher current density (900 amp/ft^2), after 4 weeks exposure air saturated water 300F—applied stress 60,000 psi.

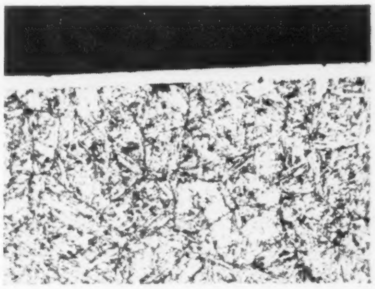


Figure 29—Same as Figure 27 but etched XT.

mium deposit, whether pre-existent, developed, or propagated during tests.

The microphotographs attached are typical for conditions indicated. Except where indicated otherwise, the depth of attack in the base metal was less than 0.5 mil (0.0005 in.), which is not significant for most applications. The typical conditions of the chromium plate after exposure of the 0.5-mil deposit as plated to the required specification at 130F and that of 160F are shown in Figures 21, 22, and 23, respectively. Figures 24 and 25 show variations in extent of attack of proprietary (source D) plate on two duplicate specimens exposed for 6 weeks. The plate thickness on both were supposed to be the same. The poorer adhesion in service of the thinner coat is apparent.

Figure 26 shows a typical effect of test conditions on the standard 2.0-mils chromium-plate as deposited by source A and B. The condition shown in Figure 27 is typical of the effects of the exposure on 2.0 mils at 160F and standard source C deposits. These two conditions and the 0.5-mil deposit at 160F (Figure 23) showed the least extent of cracking in the deposit and the lowest degree of attack on the base metal.

Figure 28 shows the greatest extent of failure of chromium plate and greatest attack on the base metal. This occurred to the specimen on which chromium was plated deliberately at a higher current density (800 to 900 amp/ft^2). The maximum depth of pitting after 4-weeks exposure was 4 to 5 mils (0.004 to 0.005 in.). In all instances the resultant corrosion of the base metal (tempered at 1125 F) was a pitting attack without any indication of intergranular attack. Two typical etched microphotographs with light and heavy pitting are shown in Figures 29 and 30. Figures 31 and 32 show accelerated failures and/or dissolution of the chromium plate at the juncture of the Stellite-6 edge to the chromium plate face. Accelerated attack (3- to 4-mils deep, maximum) also occurred in the base metal in the same areas. Base metal below the crevice proper revealed marked accelerated pitting (compare Figure 33 to 27) below cracks in the chromium plate. No attack of the chromium plate was evident in the crevice proper. Unplated AISI 410 steel (1125 F temper) showed accelerated pitting, less than 0.002 in. (Figure 34), at point of contact with edge of Stellite 6. No accelerated attack was found in the crevice proper. Except for some light general corrosion attack (rusting), bare AISI-410 steel specimens showed insignificant or no pitting attack.

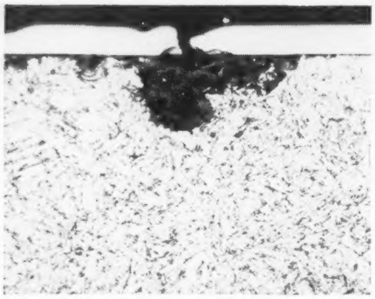


Figure 30—Same as Figure 28 but etched XT.

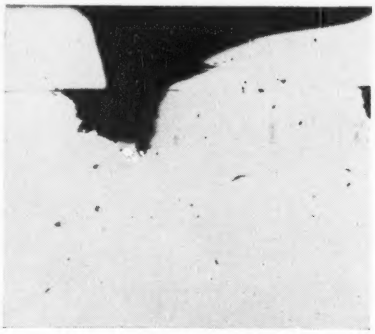


Figure 31—As polished, 250X. Stellite 6 in contact with source C—160F, 300 amp/ft^2 chromium plate on AISI 410, tempered 1125F after 6 weeks exposure 300F air saturated water—60,000 psi applied stress.

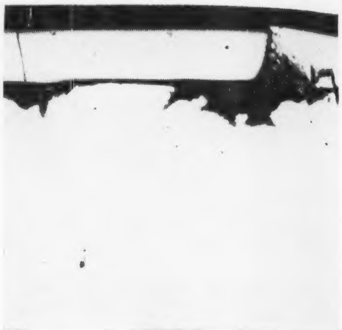


Figure 32—As polished, 250X. Stellite 6 in contact with source C—130F, 300 amp/ft^2 chromium plate on AISI 410, tempered 1125F after 6 weeks exposure 300F air saturated water—60,000 psi applied stress.

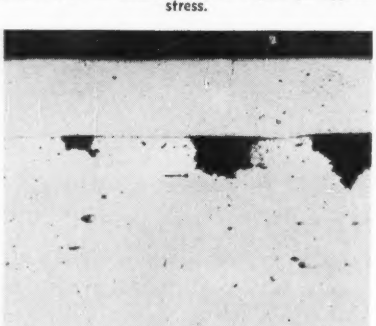


Figure 33—As polished, 250X. Stellite 6 in contact with source C—160F, 300 amp/ft^2 chromium plate on AISI 410, tempered 1125F after 6 weeks exposure 300F air saturated water—60,000 psi applied stress. (Taken below crevice area.)

Figure 34—As polished, 250X. Stellite 6 in contact with bare AISI 410, 1125F temper after 6 weeks exposure air saturated water 300F—60,000 psi applied stress.

Discussion

In deciding to use chromium plate for corrosion protection, it was known that a "good" electroplate was essential to get the desired corrosion protection. It was felt that there should be no problem in obtaining the desired deposit by using qualified platers and plating to the requirements of the detailed ASTM specification. Yet, surprisingly, it was apparent from the studies that different sources can produce chromium deposits with wide variation in appearance and characteristics even when the plating is done according to the requirements of the same detailed specification. Studies of practices used by the various plating sources revealed conformance with the requirements of the specification. As many preplating, plating, and postplating conditions have a significant effect on the characteristics of chromium electroplates,[7] it was difficult to determine with reasonable certainty the factors contributing to the wide variation in properties. These differences are considered attributable at least in part to the wide limits of the specification and/or practices and controls used in the various plating sources.

Variations in chromium deposits have produced anomalous results in studies of their protection of hardened (Rc 36-42) AISI 410 steel against stress corrosion failure. The probable reasons for these anomalous results were reviewed above in this report. It is recommended that chromium plate should not be used at present for the protection of such materials as AISI 410 steels against stress-corrosion cracking. This recommendation is based on the anomalous results with chromium plate, the failure to establish the causes for the variations, and the probability of developing cracks in the deposit when the base metal is exposed. In addition, chromium plate should not be used for corrosion protection of similar materials in oxygenated water, when in intimate contact with cobalt-base alloys.

Whenever chromium plate cracked and exposed the base metal (AISI 410 steel tempered at 1125F minimum), accelerated pitting-attack occurred. The amount of attack was dependent on the nature and the extent of the cracks rather than the duration of the exposure period. In most instances the depth of attack in the base metal was not of significance. It is very probable that longer periods of exposure in the same environment or environments of equivalent corrosive nature could eventually cause sufficient attack on the base metal to undercut and break the bond between the base metal and the chromium plate.

Before chromium plating is adopted for corrosion protection of critical stressed parts in high temperature, high purity waters, test programs to determine factors contributing to an "acceptable" deposit, and for the development of quality control procedures must be undertaken and successfully completed. It is beyond the scope of this report to discuss the many ramifications involved in such a program. The entire matter could be further complicated, if attempts are made to include an evaluation of the many proprietary plating processes and solutions extant. At some later date, it is hoped that evaluation may be made of the significance of applied stress and determination of other factors which may have contributed to anomalous stress corrosion failure and/or absence of failure of chromium-plated specimens exposed in high purity water at 300 and 600F.

Conclusions

Chromium plates should not be used for the protection of materials such as AISI 410 steel, especially if the material is anodic to chromium plate, against stress corrosion cracking in various high temperature (300 and 600 F) high purity waters. Under some conditions, it is possible to promote accelerated failures of chromium plated parts under conditions which did not cause bare material to fail. There are no advantages for the use of chromium electroplate to minimize pitting attack of AISI 410 steel (tempered at 1125F or higher) in oxygenated high temperature (300F) high purity waters.

Acknowledgments

The writer wishes to acknowledge the efforts and advice received from various members of the staff at KAPL. Special thanks go to G. E. Galonian and H. L. Tymchyn for much of the corrosion tests and data, to the Metallographic Staff of KAPL and M&P Laboratory (G.E.) for their cooperation in the preparation of microspecimens and photographs and to J. D. Dunbar for encouragement and guidance in preparation of this paper.

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Corrosion Problems in a Refinery Diethanolamine System*

By KENNETH L. MOORE

Abstract

Various corrosion problems are described which have occurred in a large diethanolamine (DEA) system that removes hydrogen sulfide from refinery gas streams and a liquid propane-butane stream. These include reboiler corrosion, rich DEA corrosion, stress corrosion cracking, and corrosion-erosion. The effect of the problems on system operation is discussed, as well as the means of minimizing the problems. Electrical resistance measuring device data indicate the importance of keeping the solution loading below 0.34 mol of acid gas ($H_2S + CO_2$) per mol of DEA to minimize the corrosion in the rich DEA. Data from this source also show the relationship between general reboiler corrosion and solution contamination. 8.4.3

Introduction

AN AQUEOUS solution of diethanolamine (DEA) is used for removal of hydrogen sulfide from refinery gases in many refineries that process sour crude oil. The weak chemical combination which results between hydrogen sulfide and DEA is easily broken by heat to release the hydrogen sulfide and regenerate the DEA for re-use. The resultant isolated hydrogen sulfide stream can then be converted into elemental sulfur or sulfuric acid by other processes. Thus, a DEA scrubbing system not only reduces the corrosivity of the refinery gases and eliminates air pollution which could result from the combustion of hydrogen sulfide-laden gases, but also can yield profitable by-products.

In the process of absorbing and stripping acid gases such as hydrogen sulfide and carbon dioxide in this aqueous system, serious corrosion problems can be encountered. Many of the problems have been reported by others. Rather than review this literature, the scope of this paper is the presentation of information obtained from an operating DEA system of recent design. It is believed that the data presented quantitatively establish limits on factors which affect corrosion.

Description of Equipment

At its Delaware Refinery, the Tidewater Oil Company has a single DEA system to remove hydrogen sulfide from refinery gases and a liquid propane-butane stream. Since the crude oil may contain as much as 4.5 percent sulfur and since the fuels produced from it are extensively hydrodesulfurized, large volumes of hydrogen sulfide are generated and must be subsequently removed from the hydrocarbon streams. The hydrogen sulfide removed by the DEA system is converted into elemental sulfur by a sulfur plant which recovers as much as 360 long tons per day.

About the Author

KENNETH L. MOORE is corrosion engineer at the Tidewater Oil Company refinery in Delaware City, Delaware. He did process design and corrosion work for three years with Atlantic Refining Company. He received a BS in chemical engineering and a' BS in metallurgical engineering at the University of Michigan in 1954.

In Figure 1, the basic DEA system is illustrated schematically. Cool lean DEA, substantially free of hydrogen sulfide, is pumped to three separate absorbers where it contacts the refinery fuel gas (vapor phase absorber), a liquid propane-butane stream (liquid phase absorber), and recycle hydrogen from one of the hydrodesulfurizers (Train V absorber). The rich DEA, after having extracted hydrogen sulfide and some carbon dioxide from these refinery streams, returns from the absorbers to the regenerator. The rich DEA passes through heat exchangers to remove heat from the lean DEA leaving the regenerator reboilers. In order to provide additional heat to adequately strip hydrogen sulfide from the rich DEA, there are three steam heated kettle-type reboilers in parallel on the bottom of the regenerator. In addition to the basic flows, the regenerator is refluxed with condensate from the overhead acid gas.

The top five bubble cap trays in the regenerator are 18 percent Cr-8 percent Ni stainless steel as are the overhead lines, accumulator (clad), reflux lines, and reflux pump. The regenerator shell and head are clad with 18 percent Cr-8 percent Ni in the same area as the alloy trays. With a few other exceptions, the remainder of the DEA system is made of carbon steel. The major vessels were stress relieved.

There are several factors which make this DEA system prone to rapid changes, and consequently demand careful attention to its operation. Since composite streams from the entire refinery are scrubbed in this system, there are many sources of contaminants. As an example, both the catalytic cracker and fluid coker generate hydrogen cyanide, carbonyl sulfide, organic acids, and ammonia. Also, the DEA has a high turnover rate. Though there are 42,000 gallons of DEA solution in the system, the high circulation rate of 2,100 gpm turns the inventory over every 20 minutes. Thus, contamination of the solution and change in strength can occur much faster than in many DEA systems.

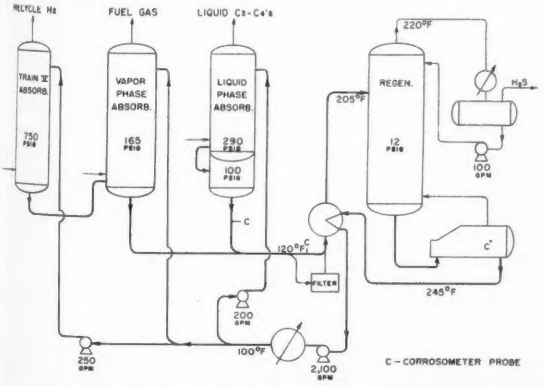

Figure 1—DEA system—Tidewater Delaware Refinery

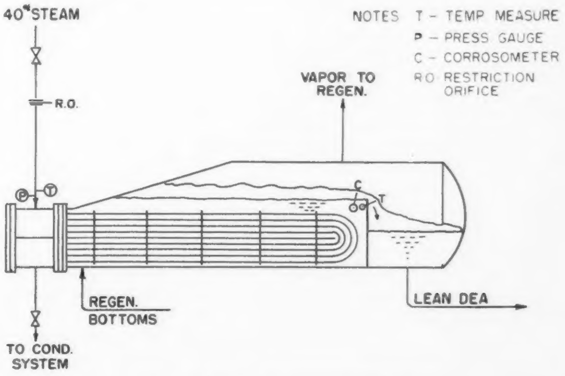

Figure 2—Details of regenerator reboiler.

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*Submitted for publication March 21, 1960. A paper presented at the 16th Annual Conference, National Association of Corrosion Engineers, Dallas, Texas, March 14-18, 1960.

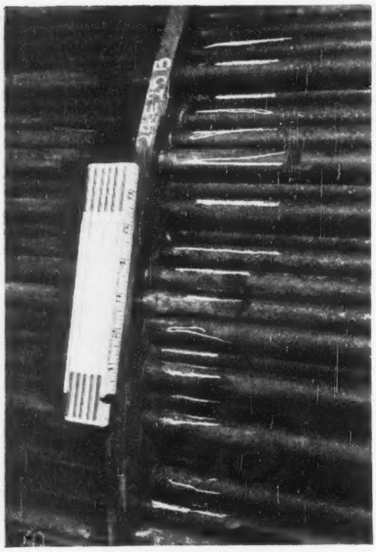

Figure 3—Regenerator reboiler bundle showing localized attack at the baffle.

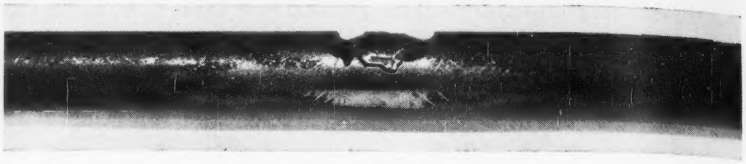

Figure 4—Single steel tube from regenerator reboiler bundle showing localized attack at the baffle.

Corrosion Problems

Corrosion has had a large and serious effect upon operation of this DEA system. Aside from failures due to loss of metal, corrosion accounts for the iron sulfide fines which cause erosion, plugging, galvanic attack, and perhaps foaming. Thus the total cost of corrosion is the cost of equipment repairs plus: (1) the cost of DEA lost from the system due to upsets, (2) the cost of lost products, (3) the cost of damage to other equipment burning unsweetened gas, and (4) the cost of filtration.

The corrosion problems can be divided into several categories, such as reboiler corrosion, rich DEA corrosion, stress corrosion cracking, and corrosion-erosion. Each of these will be discussed in detail.

Reboiler Corrosion

The first problem experienced in the system was severe localized corrosion in the regenerator reboilers. Figure 2 is a sketch showing details of the kettle-type reboilers. The 13-gauge carbon steel tubes were perforated at the baffles in the top half of each of the three bundles after 10 months of operation.

Figure 3 is a photograph of a bundle showing severe corrosion at the baffle. The steel baffles corroded as did the tubes, thus ruling out a galvanic effect between them.

Figure 4 illustrates a single tube where it passed through a baffle. The tube retained its original diameter throughout most of its length, and even at the center of the area under the baffle. The corrosion rate represented by the perforation is approximately 120 mils per year.

The corrosion resulted from local hot spots on the tubes at the baffles. Steam entered the top half of the U-tube bundle at 40-45 psig, superheated to about 350 F. There was enough clearance between the tubes and baffle to admit DEA into the annular crevices, but an insufficient flow to effect much cooling. Though the bulk DEA temperature did not exceed 245 F, the liquid in these crevices was probably around 300 F. Severe gas stripping undoubtedly resulted in the crevices, as well as concentration of contaminants. It is significant that the localized attack under the baffles occurred only on the inlet pass and was most severe at the inlet end where steam temperatures would be the greatest.

Because of the severe steam leakage and consequent dilution of the DEA solution, it was necessary to retube all three bundles with new steel tubes. To extend the service life of the bundles, the following modifications were made:

1. Heat control of the system was changed, so that the steam going to the reboilers is throttled rather than the steam condensate leaving the reboilers. This allows the bundles to operate at lower steam condensing temperatures (267 F at 25 psig versus 293 F at 45 psig). Also, the heat flux has been reduced appreciably since the entire tube surface is available for heat transfer. Previously, steam condensate flooded about one-half of the tubes and all of the heat had to be transferred in the top half of the tubes only, resulting in severe stripping due to the high heat flux. A restriction orifice, installed in the steam line to each reboiler, as shown in Figure 2, does the majority of the steam throttling.

2. The overflow weirs were raised 6 inches to create a greater head of liquid above the tubes to minimize vaporization on the tube surface.

It was not possible to install desuperheating equipment immediately, as this would have required a shutdown of the system. By the time there was a shutdown a year later, one of the reboilers had begun to leak again. However, it was observed that the severe localized corrosion was present only at the tube sheet on the inlet pass, though some general thinning had also occurred on the tubes. It was apparent that changes which had been made solved most of the problems, but it would be essential to desuperheat the steam for longer life.

After the desuperheating facilities were installed, the remaining two reboilers lasted for a total of 20-24 months, despite the attack that had already occurred.

Presently, general thinning rather than localized attack is limiting the service life of the bundle. With a life of two years with carbon steel, it is difficult to justify the use of an expensive alloy; however, alloys are being tested. A steel electrical resistance measuring probe has been installed in the hot, lean DEA as it spills over the weir, to monitor the corrosion. In Figure 5, the electrical resistance measuring device data are plotted versus time. Also plotted is the amount of solution contamination—thiocyanate (a non-volatile oxidation product of hydrogen cyanide) and DEA degradation products. There appears to be a correlation in that corrosion is virtually nonexistent when the contamination is low, whereas the corrosion rate might average about 40 mils per year with appreciable amounts of solution contamination. All other factors, such as hydrogen sulfide content and temperature, show no correlation with this general corrosion.

Solution contamination can be minimized by water washing the refinery streams before they contact the DEA solution, by side-stream distillation of the DEA solution, or by periodic discard of the DEA solution. However, the capital expenditures, DEA costs, utility costs, and possible pollution problems from the wash water, must be fully assessed to determine the most economical means to cope with the problem.

The DEA solution is dosed with 100 ppm of a water soluble filming amine inhibitor. As new DEA is added, additional inhibitor is added. No appreciable benefit has been noted in reboiler corrosion or other areas from this treatment.

Corrosion in Rich DEA

Apart from corrosion in the reboilers due to temperature and contaminants, corrosion occurs in the rich DEA which is only 100-120 F. Not only is general metal loss of concern because of the difficulty in repairing stress relieved vessels, but also localized corrosion at points of turbulence in the piping can cause unexpected failures. Perhaps the most troublesome effect of corrosion, long before replacements are necessary, is the resultant iron sulfide scale. Iron, which goes into solution due to corrosion, is precipitated out as iron sulfide of micronic and submicronic particle size. Because of its fine size, filtering is difficult. There has been considerable difficulty due to plugging of exchangers, absorbers, the regenerator, and reboilers, by the scale.

In order to determine corrosivity of the rich DEA, electrical resistance measuring probes were installed in the outlet of the liquid phase absorber and in the total rich DEA as shown in Figure 1 by the letter "C". The probe in the liquid phase absorber outlet has been installed for the longest period and has yielded the most significant data.

Figure 6 illustrates the correlation found between the acid gas loading of the DEA and the corrosivity. The acid gas loading is expressed as mols of hydrogen sulfide (plus carbon dioxide, if present) per mol of "free" DEA. In the

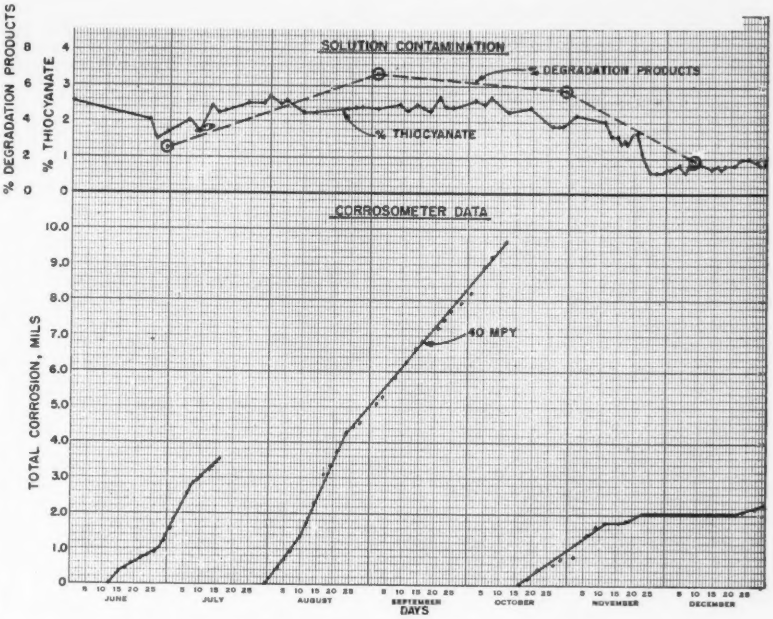

Figure 5—Relationship of corrosion in hot lean DEA and solution contamination.

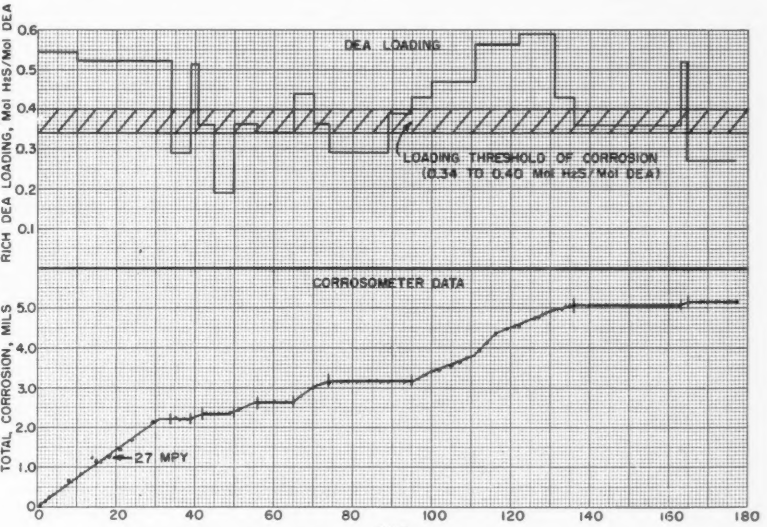

Figure 6—Relationship of rich DEA loading and corrosion.

liquid phase absorber, the acid gas absorbed is almost entirely hydrogen sulfide. It is apparent in the graph that above a loading of 0.40 mols of H_2S/mol of DEA, the electrical resistance measuring device indicates active corrosion, as much as 36.5 mils per year. Below a level of approximately 0.34 mols of H_2S per mol of DEA, there is no corrosion which is indicated by the plateaus on the total corrosion curve.

It is obvious that erosion from the solution velocity has no appreciable effect on metal loss of the probe, since the reading stays constant when the loading is below 0.34 mols/mol. In the range between 0.34 and 0.40, corrosion may or may not exist. It is believed that this band exists due to analytical inaccuracies in determination of gas loading and "free" DEA strength.

The sensitivity of the probe is indicated by the offset in the "no-corrosion" plateaus which was caused by a high acid gas loading for only two days (at 163-165 days). Also of interest is the fact that the probe is upstream of the control valve, and indicates corrosion even though the solution is under 85 psig pressure, a condition which would maximize the amount of hydrogen sulfide held in solution.

These data substantiate the "rule of thumb" that has been determined by others from extensive plant experience in which the maximum safe loading is empirically set at one-third mol per mol. It is surprising that there is such close agreement. The author believes that 0.34 mols of acid gas per mol of DEA is an important figure to consider as maximum loading in design and operation of DEA systems. Other than reboiler corrosion which is due to different factors, the loading in the rich DEA is perhaps the difference between the troublesome and troublefree DEA systems.

A number of changes can be made to increase the safe capacity of a DEA system, so that the rich loading will not exceed 0.34 mols per mol. The two most obvious changes are increased circulation rate and increased DEA concentration. The safe capacity of the system has been increased satisfactorily by operating with 30 wt. per cent DEA and greater flow rates after installing a larger booster pump for the liquid phase absorber. It is also important to balance flows to separate absorbers so that with a limited flow, the loadings in each absorber can be equalized as much as possible.

Another change which is possible for some refineries is conversion to MEA (monoethanolamine). Because of the lower molecular weight, MEA has 72 per cent more mols than DEA for the same weight percent solution. Each MEA mol has the same absorptive capacity as a DEA mol if not a little more because of its stronger basicity. However, a major consideration to be evaluated before making such a conversion is the amount of carbonyl sulfide in the streams being scrubbed. It has been reported that carbonyl sulfide combines irreversibly with MEA to form diethanolurea.[1] The cost of MEA consumption as well as the cost of removal of the by-product from the solution must be considered before the conversion is made.

Stress Corrosion Cracking

The need to stress relieve welded vessels for an amine system has been reported in the literature.[2] The residual stresses are sufficient to cause stress corrosion cracking. No trouble of this nature has occurred in the company's stress relieved vessels; however, some of the regenerator internals have failed for this reason. The steel yokes which hold the bubble caps and risers in place on the regenerator trays have cracked. Apparently, there is sufficient stress induced when assembling the bubble cap trays to cause stress corrosion cracking in this vapor zone. In the first year of operation, approximately one-third of the yokes were broken, allowing the cap and risers to move about.

A typical fractured yoke is shown in Figure 7. In most cases there was only minor, if any, metal loss at the fracture. Minor pitting is apparent. Due to the unavailability of alloy yokes during the first shutdown, replacements were made with steel again. All yoke tips were tested with pliers to determine where cracks existed though complete separation had not occurred.

As expected, the problem was not solved. Many of the yokes broke again.

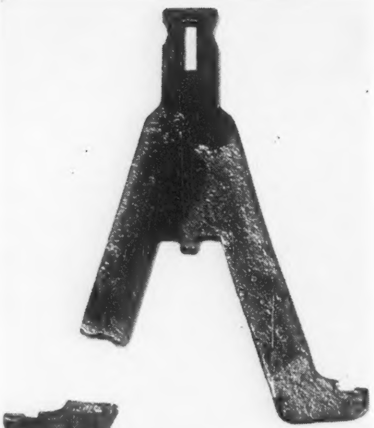

Figure 7—Stress corrosion cracking of steel yoke in regenerator bubble cap trays.

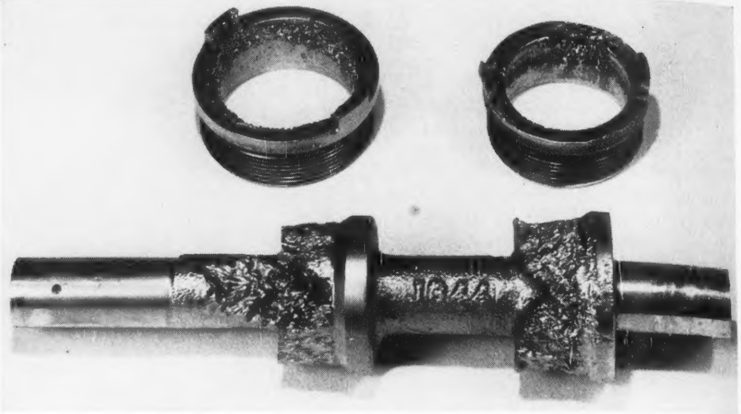

Figure 8—Control valve plug and seats showing corrosion-erosion.

Type 304 stainless steel yokes have now been installed. This alloy has performed well in the top section of the regenerator, without a single failure.

Corrosion—Erosion

In the hydrodesulfurizer absorber, a high pressure must be maintained since the hydrogen is recycled to the process after scrubbing. Thus the rich DEA must be depressured to re-enter the DEA system. This is done through the level control valve. Figure 8 illustrates the damage done to this double V-port valve in only 14 months of service. The plug and seats are made of Type 316 stainless steel with Stellite hard facing. In general, Stellite withstood the attack, but it also began to deteriorate in areas. Reduction of solids, lower acid gas loadings, and a change in valve design have contributed to longer life. If this is not adequate, a solid Stellite plug will be tested.

The main lean DEA circulation pumps were originally steel with cast iron impellers. After approximately 10 months of service, corrosion-erosion had destroyed the cast iron impellers. Replacement with Type 304 stainless steel has greatly extended the service life; however, some attack still occurs, particularly on the Type 304 wear rings.

Miscellaneous

The rich to lean DEA heat exchangers have experienced only minor corrosion problems, though they are constructed of steel. Some galvanic attack is apparent where breaks have occurred in the sulfide scale. Localized pitting has occurred in an area where poor pump suction conditions allow the hot lean DEA to vaporize. The major problem in these exchangers has been plugging due to iron sulfide fines.

Summary

Corrosion control plays a large role in efficient operation of a DEA scrubbing system. Equipment corrosion failures obviously incur repair costs as well as operational upsets which result in solution loss, product loss, pollution, and corrosion of other equipment. Corrosion also generates scale in the DEA solution which causes plugging, erosion, galvanic attack and perhaps foaming.

Varied corrosion problems have been encountered and minimized in the following manner.

1. **Reboiler Corrosion**—Localized attack occured on the steel tubes resulting from hot spots at the baffles. This has been prevented by desuperheating the steam, operating at as low a steam pressure as possible, keeping the tubes free of condensate, and increasing DEA liquid height above the tubes. Electrical resistance measuring probe data indicate that general thinning is a function of the solution contamination resulting from DEA degradation products and contaminants extracted from the refinery streams.

2. **Rich DEA Corrosion**—Probe data show that corrosion is a function of the acid gas loading in rich DEA. Below 0.34 mols of acid gas per mol of "free" DEA, there is no corrosion. Existing systems which exceed this loading can be rectified by using a higher concentration of DEA, a higher circulation rate, or by conversion to MEA.

3. **Stress Corrosion Cracking**—Steel yokes, which retained the bubble caps in the regenerator, failed by stress corrosion cracking. They have been replaced with Type 304 stainless steel yokes.

4. **Corrosion-Erosion**—A control valve, which throttled high pressure DEA, suffered severe corrosion-erosion of the hard-faced Type 316 stainless steel plug and seats. Reduction of solids, acid gas loading, and change in design have given longer life.

Cast iron impellers in the main circulation pumps, which failed from corrosion-erosion in 10 months, have been replaced with Type 304 stainless steel to provide much longer life.

The electrical resistance measuring device has proven to be a valuable, sensitive tool to establish factors affecting corrosion in a DEA system and to monitor the effectiveness of corrosion control.

Acknowledgment

The analytical and technical assistance by the ethanolamine manufacturers is acknowledged and appreciated.

References

1. N. C. Updegraff, R. M. Reed. Twenty-Five Years of Progress in Gas Purification. *Petroleum Engineer*, **26**, No. 10, C57-C58 C60-C63 (1954) September.
2. G. L. Garwood. What to Do About Amine Stress Corrosion Cracking. *Oil and Gas Journal*, **52**, No. 12, 334-340 (1953) July 27.

DISCUSSION

Question by Giles A. Rawls, Port Arthur, Texas:

You mentioned that you had used 100 ppm inhibitor in DEA solution and did not realize any benefit. Did you use electrical resistance measuring probe to determine whether it was beneficial or not?

Reply by K. L. Moore:

Yes. We had probe in system before adding inhibitor and after adding inhibitor and could not determine any difference in the corrosion rate.

Any discussion of this article not published above will appear in June, 1961 issue.

Compatibility of Materials With Unsymmetrical Dimethylhydrazine Rocket Fuel*

By ***C. W. RALEIGH*** *and* ***P. F. DERR***

Abstract

Extensive laboratory tests on the compatibility of metals, elastomers and plastics with unsymmetrical dimethylhydrazine (UDMH) are summarized. Materials service history obtained during six years' plant production is also reported. UDMH was found to be compatible with almost all metals. Elastomers and plastics which are compatible with UDMH include butyl rubbers, Hydropol-T, Teflon, unplasticized Kel-F and polyethylene. 4.4.8

Introduction

UNSYMMETRICAL dimethylhydrazine is one of the newer liquid rocket chemical fuels in operational use in the United States today. The transition of this fuel from a laboratory chemical to commercial production and large scale use was made in less than three years.

The Chlor-Alkali Division of Food Machinery and Chemical Corporation pioneered in the commercial manufacture of Dimazine* or UDMH in 1954. Metal corrosion information and other materials-of-construction data were required for the design and construction of the plant and for proper storage, shipping and handling of this fuel. This is a report of part of the materials compatibility information developed by the author's company over the past six years. In addition to extensive coupon test data, experience in storage, shipping and handling of tank car quantities of UDMH is reported.

The rapid acceptance of UDMH as a high energy storable liquid propellant is attributable in part to its compatibility with almost all metals under normal environmental conditions. However, UDMH is an excellent solvent for many plastics and rubbers, and extensive testing was required to find plastics and elastomers which were compatible. Teflon, polyethylene, and butyl rubbers have given the most satisfactory service.

Although all the defense agencies and all major liquid rocket engine companies have worked with UDMH and have developed some information on compatibility of metals and elastomers with this fuel, nearly all of this information remains "buried" in a multitude of classified reports. Most of the available unclassified information is found in manufacturers' bulletins,[1,2] articles published by manufacturers' personnel[3,4,5,6] or in compilations and handbooks based on manufacturers' information.[7,8,9,10]

In general these references simply list recommended materials of construction, without reporting details of their experimental test conditions and results. Exceptions include (a) a recent release through the Liquid Propellant Information Agency of three unclassified technical notes[11,12,13] by Army Ordnance Missile Command reporting their laboratory test information on compatibility of materials in their Jupiter-C missile with UDMH and the U-DETA blend (60 percent UDMH-40 percent diethylenetriamine; and (b) a series of reports by the Connecticut Hard Rubber Company of work performed for the Wright Air Development Center on the compatibility of UDMH and other fuels with elastomeric compounds.[14,15,16]

Derr

Raleigh

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CHARLES W. RALEIGH is a chemical engineer in the Inorganic Research and Development Department of the Food Machinery and Chemical Corporation, Princeton, N. J. His work is in liquid propellants for missiles. He has a BS in chemical engineering from Northeastern University and is a member of ACS and the American Rocket Society.

Physical Properties as Related to Materials Compatibility

A list of physical and chemical properties of UDMH of interest to the corrosion or materials engineer are given in Table 1. UDMH is a pure compound with the structural formula $(CH_3)_2NNH_2$. Chemically it is a weak organic base,[17] $pK_b = 6.8$, but exhibits basic attack on reactive metals such as aluminum only in water solutions. Because UDMH is a hygroscopic material it must be stored in a closed system to prevent pick up of moisture from the atmosphere. UDMH is also a good reducing agent and reacts slowly with the oxygen in air to form dimethylmethylene hydrazine, $(CH_3)_2NN=CH_2$, and minor amounts of a number of other compounds which may include diazomethane, ammonia and polymethylenes.[18] This is a secondary reason for normally storing UDMH under a nitrogen blanket. (The primary reason is the flammability of UDMH discussed below.) Carbon dioxide cannot be used for blanketing because it reacts with UDMH to form a carbazate salt.[19]

UDMH is an endothermic compound with a heat of formation (ΔH) of

TABLE 1—Physical Properties of UDMH

Property	Metric Units	English Units
Molecular Weight	60.08	60.08
Density	0.784 g/ml at 25C	6.64 lb/gal at 60F
Boiling Point	63C	146 F
Freezing point	—57C	—71F
Vapor pressure	157 mm at 25C	98 mm at 60F
Viscosity	0.51 cps at 25C	0.59 cps at 60F
Flash point (Tag closed cup)	1C	34F
Flammability limits, Temp.	—15C to 60C	5F to 140F
Flammability limits, Conc.	2 to 100%	2 to 100 vol. %
Spontaneous ignition in air	250C	482F
Spontaneous decomposition in N_2	> 600C	1112F
Shock sensitivity	Not detonable even with 100 g tetryl charge	Not detonable even with 100 g tetryl charge
Critical temperature	250C	482F
Critical pressure	53.5 atmospheres	786 psia
Heat of Formation (ΔH)	12.74 Kcal/mole at 25C	381 BTU/lb at 77F
Heat of Combustion (ΔH)	—474.11 Kcal/mole at 25C	—14,200 BTU/lb at 77F
Basicity, pK_b	6.8	6.8
Dielectric constant	3.5	3.5
Hydroscopicity, 24 hrs. at 27C and 70% Relative Humidity	0.4 wt. % H_2O/ 200 ml sample	0.04 wt. % 51 Gal. sample
Solubility, in water	Completely miscible	....
Solubility, in ethanol	Completely miscible	....
Solubility, in kerosene	Completely miscible	....

★Submitted for publication March 7, 1960. A paper presented at the 16th Annual Conference, National Association of Corrosion Engineers, Dallas, Texas, March 14-18, 1960.

*Dimazine is the registered trademark of Food Machinery and Chemical Corporation. For convenience, UDMH will be used throughout this article to designate unsymmetrical dimethylhydrazine.

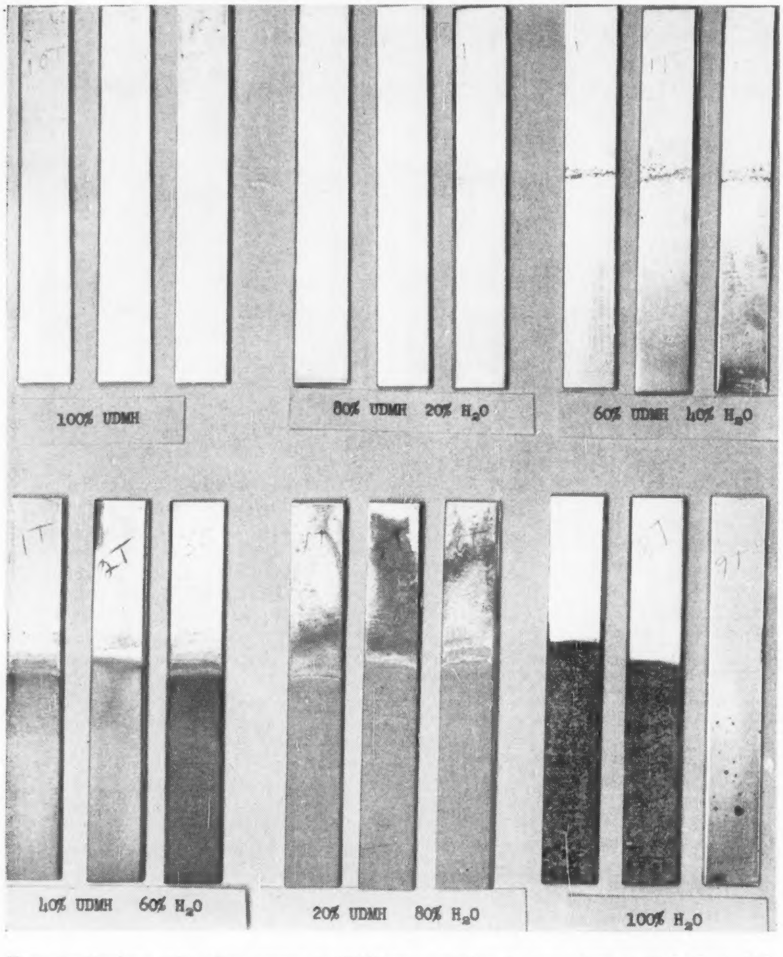

Figure 1—Aluminum strips after exposure to UDMH-water solutions for seven days at 63 C (front side).

+12.735 Kcal per mole at 25 C. Nevertheless it is a surprisingly stable compound with a decomposition temperature greater than 600 C or 1112 F,[19] and a spontaneous ignition temperature in air of 250 C, or 482 F. For all practical purposes it is insensitive to shock, since it is not detonated even by a 100g tetryl charge. However, UDMH has very wide flammability limits in air, (i.e., 2 to 100 percent). To avoid possible ignition by static or other spark sources, it is almost always handled under a blanket of nitrogen gas.

UDMH is completely miscible with both polar (water, ethanol) and nonpolar (hydrocarbon) solvents. UDMH is unique in these solvent properties among currently used rocket fuels. Therefore finding elastomers, sealants and lubricants compatible with UDMH has been a somewhat greater problem than finding metals compatible with UDMH. Many butyl rubbers, Teflon, polyethylene, and some unplasticized Kel-F's have been found satisfactory.

On the basis of the physical and chemical properties of UDMH described above it might be anticipated that the reducing action of UDMH might lead to reaction with metal oxide coatings such as copper oxides, especially at elevated temperatures. Also the combination of hygroscopicity and weak basicity might be expected to cause corrosion of electronegative metals such as aluminum, magnesium and zinc. As described below UDMH in aqueous solution does attack aluminum, but all these metals are compatible with anhydrous (commercial) UDMH.

Electrolytic corrosion has not been studied here, but it could be expected to be very low in anhydrous UDMH because of the low conductivity of UDMH. Moisture pick-up would of course promote electrolytic corrosion.

Laboratory Corrosion Tests

Metals

Corrosion rate determinations were made on a number of metals using test coupons approximately ½" x 3" x 1/16". In general exposure tests were for 28 days at 30 C and 7 days at 63 C (UDMH reflux temperature). The 30 C samples were completely immersed in UDMH. The 63 C samples were immersed to a depth of 1½" in the liquid. In a few cases, the UDMH was assayed before and after the test, to confirm that the test conditions had no effect on the stability of the UDMH.

TABLE 2—Aluminum Alloys—Compatibility with UDMH

Alloy	Corrosion Rate, IPY 28 Days at 30C (86F)	Corrosion Rate, IPY 7 Days at 63C (146F)
1100-H14	<.0001	<.0001
1260-H14	<.0001	.0002
2024-T3	<.0001	<.0001
3003-H14	<.0001	<.0001
3004-H34	.0005	.0001
5052-H34	.0003	<.0001
5086-H34	<.0001	.0003
5154-H34	.0001	.0002
6061-T6	.0002	<.0001
6063-T6	<.0001	<.0001
7075-T6	<.0001	<.0001
43	.0004	.0010
356-T6	.0009	.0016

TABLE 3—Mild and Stainless Steels—Compatibility with UDMH

Alloy	Corrosion Rate, IPY 28 Days at 30C (86F)	Corrosion Rate, IPY 7 Days at 63C (146F)
Mild Steel	<.0001	......
4130	<.0001	......
A 286	<.0001	......
302	<.0001	......
303	.0001	.0004
304	<.0001	......
316	<.0001	......
347	<.0001	......
416	.0013	.0001
422	.0003	.0001
PH 15-7-Mo	<.0001	......
17-7-PH	<.0001	<.0001
Haynes Alloy 25 (No. Mo)	<.0001	<.0001
Hastelloy F (6.5% Mo)	<.0001	<.0001
Hastelloy X (9% Mo)	<.0001	<.0001
Hastelloy C (17% Mo)	<.0001	<.0001
Hastelloy B (28% Mo)	<.0001	<.0001

Of the 41 alloys tested, none showed any appreciable corrosion rate after exposure to anhydrous UDMH at 30 C and 63 C. No change was found in UDMH assay within the accuracy of the analytical method. The metals shown to be satisfactory in these tests included pure aluminum and its alloys, the 300 series stainless steels, 416, 422, A286, 4130, 15-7 PH and 17-7 PH steels, Hastelloys B, C, F, and X, commercially pure titanium and its alloys C120 AV and B120 VCA. The data which are given in Tables 2, 3 and 4 show that most of the wrought alloys had corrosion rates of 0.0003 ipy or less.

Because of the mild basicity of UDMH, it was anticipated that UDMH-water solutions would attack aluminum. To confirm this, test coupons of aluminum alloy 1260-H14 were exposed to UDMH—deionized water solutions at 30 C and 63 C. Corrosion rates could not be calculated because most of the samples gained weight. The scale buildup was proportional to the water content of the UDMH. The maximum scale buildup observed was estimated to be about 0.005 inch per year. Figure 1 shows the aluminum test strips after 28 days' exposure to anhydrous UDMH, UDMH-water solutions, and to deionized water. It is seen that the aluminum was unaffected by anhydrous UDMH and most severely attacked by the deionized water.

TABLE 4—Miscellaneous Alloys—Compatibility with UDMH

Alloy	Test Conditions		Corrosion Rate, ipy	UDMH Assay
	Time (Days)	Temp., Degrees C		
Titanium A-55	7	63	.0002	....
Titanium A-55	28	30	<.0001	....
Titanium C-120 AV	7	63	<.0001	....
Titanium C-120 AV	28	30	<.0001	Before 98.8 After 98.8
Titanium B-120 VCA	7	63	<.0001	....
Titanium B-120 VCA	28	30	<.0001	Before 98.8 After 98.8
Inconel	2	63	......	Before 99.3 After 99.1
Magnesium	28	30	<.0001	Before 99.7 After 99.7
Monel	2	63	......	Before 99.3 After 99.4
Copper	2	63	.0003	Before 99.3 After 98.9
Red Brass	2	63	......	Before 99.3 After 99.5

Plastics and Elastomers

Plastics and elastomers were evaluated using standard ASTM dumbell samples. These were completely immersed in anhydrous UDMH for 28 days at 30 C and in the case of the more promising materials, for 7 days at reflux temperature. Following exposure, samples were tested for changes in weight, thickness, hardness, tensile strength, and percent elongation. Of the more rigid plastics, Teflon, Mylar A, Kel-F 300, and Dapon showed excellent resistance to UDMH. However, Kel-F 800 and polyvinyl alcohol completely dissolved in less than 2 hours at room temperature.

Service Experience

In the spring of 1954, the Chlor-Alkali Division of Food Machinery and Chemical Corporation built and started operation of a semi-commercial plant for production of UDMH within a period of only six weeks. This tight schedule permitted making only minor additions and revisions to an existing general-purpose chemical pilot plant, which was fabricated of Pyrex glass pipe, glass-lined steel and stainless steels (304, 316 and 347). Teflon and polyethylene gaskets were shown to be relatively unaffected by immersion in UDMH and were therefore employed in this operation. This plant was operated for a period of two years and the replacement materials of construction were changed during this time to less costly materials, such as mild steel instead of 304 stainless for storage and shipping containers, and polyethylene and Garlock 735 and 900 in place of Teflon for gaskets. The ICC-5C-304 stainless steel, returnable drums employed for the initial shipments of UDMH were replaced with ICC-17C mild steel, non-returnable drums in 1955.

In early 1956, FMC started operation of a commercial size plant for UDMH at its Baltimore location. The capacity of this plant was tripled in 1958. In this original Baltimore plant and in all its expansions, mild steel has been employed for the final purification-distillation unit and for all product storage and handling facilities. Mild steel tank cars have been successfully employed for shipments of UDMH or blends (with diethylene triamine, DETA) since the fall of 1956. These welded steel tank cars are fitted with Teflon gaskets and employ top unloading through steel cocks with Teflon sleeves. Bulk storage facilities include 5,000 and 10,000 gallon mild steel storage tanks.

Metals

Tests were completed recently on the long term storage of UDMH in mild steel 55-gallon drums at outdoor ambient temperatures (Baltimore, Maryland) for 18 to 25 months.[1] In summary the tests showed that UDMH after storage for this period was still clear and colorless and met the requirements of military specification MIL F-25604B, 12 September 1958. There was no build-up of pressure during this storage period, and close inspection of the drums at the completion of the tests showed no internal corrosion of the drums (Figure 2).

Confirmation of the good storability of UDMH in 55-gallon steel drums has been obtained at Wright Air Development Center. WADC personnel have reported verbally that they stored six 55-gallons drums of UDMH at 140 F for three months and then at 160 F for an additional two months. The six 55-gallon drums under test consisted of two clean mild steel drums, two rusted mild steel drums, and two clean stainless steel drums. There was no pressure build-up in any of these drums during the five month test period. WADC personnel concluded that the mild steel drums were equally as good as stainless steel drums for storage of UDMH even at elevated temperatures.

Information on the long term storage of UDMH in aluminum (alloy 1100) containers was obtained in cooperation with a customer who was loading 1.07 pound quantities into the small aluminum bottles which are employed to charge the Nike-Ajax with a hypergolic starting slug.

After 18 month storage in the aluminum bottle, the UDMH developed a light yellow color, but otherwise met all the military specifications. (Color development is usually attributable to slight air oxidation.) Very recently, the Naval Ordnance Test Station has reported that they successfully stored UDMH in aluminum for three years in a canned liquid rocket engine.[20]

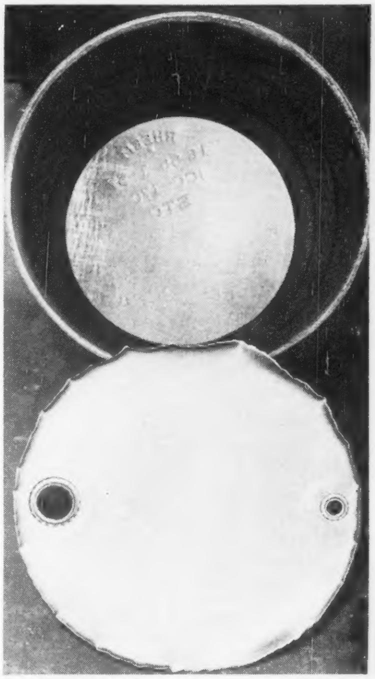

Figure 2—Inside and head of Drum No. 2 after storage of UDMH for 18.5 months.

Materials of Construction Employed by Missile Manufacturers

Although mild steel equipment is used almost exclusively for manufacture, handling and shipping of UDMH, missile manufacturers have employed either stainless steels or aluminum alloys because of their greater strength to weight ratio. Ground handling equipment has also normally been fabricated of stainless steel (usually 304) or aluminum to minimize atmospheric corrosion problems, and in some cases provide air transportability. Information published in the open literature on materials of construction employed with UDMH in unclassified missile applications is described below.

Bomarc-A

This missile employs a liquid rocket booster engine using as fuel a mixture of 40 percent UDMH and 60 percent JP-4 (kerosene) sometimes called "JP-X Fuel." The rocket sled version of the Bomarc engine employs 6061-T6 aluminum for the propellant tankage.[21] The ground handling truck tankage is made of 347 stainless steel and commercial tank trucks of 304 stainless have been employed to transport the fuel mixture to the Bomarc sites.

Vanguard and Thor-Able

The second stages of the Vanguard and Thor-Able missiles employ the Aerojet-General Able engine using 100 percent UDMH as the fuel. Both the UDMH missile tankage and the fueling trailer tankage were constructed of stainless steels.[22]

Nike-Ajax

This missile employs 100 percent UDMH as a starting "slug" and a mixture of 17 percent UDMH—83 percent JP-4 (M-3 fuel) for the sustainer engine fuel. Both fuels are packaged in aluminum containers holding a "unit" charge

TABLE 5—Plastics and Elastomers—Compatibility with UDMH

	Test Conditions				Hardness			Tensile Strength			Ultimate Elongation	
Material	Time, Days	Temp., Degrees C	Weight Change Percent	Volume Change Percent	Initial Duro A Points	Final Duro A Points	Change, Percent	Initial psi	Final psi	Change, Percent	Final	Change, Percent
Dapon B887-106B	28	30	0	0	..	..	....	....	....	....	...	......
Kel-F 300	28	30	0	0	95	96	+ 1	....	....	....	...	......
Kel-F 800	1	30			sample completely dissolved							
Mylar A	28	30	0	0	..	..	....	....	....	....	...	......
Polyvinyl alcohol	1	19			sample completely dissolved							
Teflon	28	30	0	0	93	93	....	....	....	....	...	......
Butyl Rubbers:												
Firestone Rubber D432	28	30	5.6	2.5	55	45	—18	1835	1543	—16	540	none
Parker 37014	28	30	1.4	3.8	59	53	—10	1153	888	—17	670	10
Precision Rubber 925-70	28	30	8.5	16	69	52	—25	1860	1222	—34	500	......
Stillman Rubber 613-75	7	30	6.4	14	77	58	—24	1958	1089	—44	...	......
Thiokol C-55935	28	30	6.6	....	75	63	—16	1235	....	....	187	—7
Kel-F 5500	2	30			samples completely dissolved							
Polyvinyl chloride (Tygon 3603)	49	30			sample completely deteriorated							
Silicone DC 152	7	30			sample completely deteriorated							
Buna N	12	28			sample severely swelled							
Hydropol T	28	30	4.0	7.9	88	84	—4.5	2477	2431	—2	280	+4

TABLE 6—Sensitivity of UDMH and Hydrazine to Copper and Molybdenum Oxides

	Observation	
Oxide	Hydrazine	UDMH
Molybdenum oxide (MoO_3)	Immediate ignition	No visible effect
Cupric oxide wire (CuO)	Vigorous reaction-much fuming, but no fire	No visible effect
Cuprous oxide powder (Cu_2O)	Immediate reaction Ignition after 30 seconds	No visible effect

(i.e., the 1.07-lb. hypergolic starting slug is packaged in an 1100-aluminum bottle and the M-3 fuel in a 9-gallon drum constructed of 5052 and 6061 aluminum.[23])

Jupiter-C

The Army's Jupiter-C missile which placed the Explorer satellites in orbit employed a fuel mixture of 60 percent UDMH and 40 percent diethylene triamine (DETA) in the first stage.

The first stage of this missile was an elongated Redstone missile which normally employs 75 percent alcohol as fuel. The 60 percent UDMH-40 percent DETA fuel gave a higher thrust which was essential for success of the satellite missions. The 60 percent UDMH-40 percent DETA (U-DETA Blend) was substituted directly for the 75 percent alcohol fuel with no changes in hardware. Information on the compatibility of the aluminum (anodized 2014, 2017, 2024, 6061, 7075 and 356) and 18-8 stainless steel components of this missile with UDMH and the U-DETA Blend has been reported by W. A. Riehl.[13,24] The Army's 5000-gallon tank trucks employed to transport the U-DETA Blend from the railroad tank cars to the launching pad were constructed primarily of 5052-aluminum in order to be air-transportable.[10]

Bullpup and Sparrow

The Reaction Motors Division of Thiokol has developed pre-packaged liquid rocket engines which are to replace solid motors now used in Bullpup and Sparrow III.[25] UDMH is one of the components of the "mixed amine fuels" employed in these engines. The fuel tankage for these missiles is fabricated of 6066-T4 aluminum.

Rascal and Agena

Bell Aircraft has employed UDMH as hypergolic igniter in its Rascal missile and as a primary fuel in its Agena rocket motor employed in the Discoverer satellite program. They have employed mainly aluminum alloys for construction of parts contacting UDMH.[26]

New Missile Developments

The Naval Ordnance Test Center has recently published their work on "canned" liquid rocket engines[20] and on a variable thrust rocket engine.[27] UDMH has been shown to be one of the best fuels available to date for both these systems. It has also been announced very recently that both the Aerojet and Bell Aircraft UDMH rocket engines have been converted to "restartable" systems. The corrosion problems in these newer systems are minor since they involve adaptation of aluminum and stainless equipment of proven serviceability.

Conversion of large liquid missiles from cryogenic propellants to storable propellants has been under consideration for some time. The excellent compatibility of UDMH with all the stainless steels and high-strength aluminum alloys employed in these missiles has placed UDMH at the top of many lists of recommended storable fuels.

Summary

Mild steel, stainless steels, aluminum alloys and titanium alloys are suitable metals for storage of anhydrous UDMH rocket fuel for periods of at least three years. However, aqueous solutions of UDMH attack aluminum alloys.

The unique solvent properties of UDMH (completely soluble in both polar and non-polar liquids) limit the plastic and elastomeric materials which may be used as materials of construction. Teflon, polyethylene, Dapon, Mylar A and Kel-F 300 are suitable semi-rigid plastics under ambient conditions. Many but not all butyl rubbers and Hydropol T appear to be the best elastomeric materials for use with UDMH. Most silicone rubbers, Buna N rubbers, plasticized fluorocarbon elastomers (Kel-F 5500) and polyvinyl chloride plastics are grossly attacked by UDMH.

It is planned to continue to evaluate new materials for use with UDMH as they are brought to the authors' attention.

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DISCUSSION

Question by Earl L. White, Columbus, Ohio:

What is the effect of UDMH on copper alloys? Is there any catalytic effect by copper on molybdenum which tends to break down UDMH?

Reply by Paul Derr and Charles Raleigh:

At normal storage temperatures neither pure copper nor molybdenum show any appreciable decomposition of unsymmetrical dimethylhydrazine. In one test at Food Machinery and Chemical Corporation, UDMH was boiled for 47 hours in the presence of a copper strip. The concentration of the UDMH was 99 percent before and after the test period. There was a trace of red sediment (believed to be finely divided copper metal formed by reduction of the copper oxide surface of the test specimen) in the UDMH at the end of the test. The weight loss of the copper strip corresponded to a corrosion rate of 0.0003 ipy. In a similar test with red brass no corrosion was observed and there was no change in UDMH concentration after two days in boiling UDMH.

We have also conducted tests with molybdenum pellets immersed in UDMH for 28 days at room temperature. The UDMH initial and final concentration was 99.6 and 98.7 percent respectively. The corrosion rate was calculated to be 0.0013 ipy. Similar tests with high molybdenum alloys (Hastelloy B-28 percent molybdenum) showed no change in UDMH concentration and a corrosion rate less than 0.0001 ipy.

Beaker tests were made to estimate the relative sensitivity of hydrazine and UDMH to decomposition by oxides of molybdenum and copper. 0.5 g of the oxide was placed on a watch glass and 5 drops of fuel added to the oxide. The mixture was observed from behind a glass explosion shield. The tests were discontinued if no evidence of reaction was noted in 5 minutes. The results are shown in Table 6.

It was concluded that the UDMH was much less sensitive to decomposition by these chemicals than hydrazine. However, since the latter tests were of very short duration (5 minutes), we do not know what effect these oxides might have on UDMH decomposition on long exposure.

More extensive tests of copper and molybdenum are in progress.

Any discussion of this article not published above will appear in June, 1961 issue.

Part 4—Wrought Iron

Corrosion of Metals in Tropical Environments★

By C. R. SOUTHWELL, B. W. FORGESON and A. L. ALEXANDER

Introduction

A SERIES of long-term studies was initiated in the Panama Canal Zone in 1946 to establish the corrosion rates of approximately fifty different metals and alloys in five natural tropical environments. These environments include sea and fresh water, continuous immerison, mean tide, and marine and inland atmospheres. Earlier reports in this series[1, 2, 3] have described in detail the methods and procedures used. Also, results from the eight-year exposure have been reported for five pure (unalloyed) metals[1] and for ten structural steels, both exposed to the atmosphere[2] and submerged.[3]

There has been considerable speculation regarding the corrosion of wrought iron in comparison with modern structural steels. Although there is much evidence of excellent service from old French wrought iron structures in Panama, quantitative data on the corrosion rates of wrought iron compared to steel in these tropical environments is unavailable and was naturally unattainable from examination of the enduring structures. Therefore, it was considered desirable to include wrought iron in all phases of this corrosion investigation.

This report evaluates, from results of controlled studies, the comparative corrosion rates of modern Aston-process wrought iron and structural steel, in five tropical environments. Ten structural steels of different composition were included in the complete investigation; data describing the comparative corrosion resistance in these same environments have been published in previous reports of this series.[2, 3] In this report, data for several of these steels will be included for comparison with wrought iron. Since the price of wrought iron equals or exceeds the price of any of the structural steels, selection of a reference material was not dictated by economic considerations. In atmospheric tests[2, 4, 5, 6] the high corrosion resistance of proprietary low-alloy steels has been established and since four steels of this type were included in this study, wrought iron is compared with this group of low-alloy steels in the atmosphere. Underwater corrosion studies[3] revealed that mild unalloyed carbon steel is equal or superior to steels containing low percentages (less than 5 percent) of alloying elements, and therefore this mild steel was selected as the reference material for comparing durability of wrought iron in the immersion tests.

Abstract

This paper discusses the corrosion of Aston process wrought iron when exposed to five natural environments in the tropics. Data are reported covering an exposure period of eight years during which the metal was immersed at mean tide and continuously in fresh water and in the sea. Data are presented also from atmospheric exposures including both marine and inland atmospheres. Results indicate that corrosion (measured by weight loss) in fresh water is about equal to that which occurs at mean tide, while corrosion proceeds at the greatest rate during continuous immersion in the sea. Millscale on wrought iron accelerates pitting most severely on metal immersed continuously in the sea, although to a lesser degree than structural steel similarly exposed. It is suggested further that during the earlier exposure of wrought iron and mild steel to tropical water there is little difference in the rates at which the two metals corrode. After eight years, however, the steel shows a significantly greater weight loss. The corrosion of metallic couples of wrought iron and carbon steel in both fresh water and sea water is discussed. 4.2.7

Test Conditions

Exposure Environments

At the Gatun Lake and Fort Amador water immersion sites, the water was sampled at the elevation of the exposure racks each March (during the dry season), May (beginning of the wet season), and November (end of the wet season) during the period May 1946 to March 1951. These data were summarized for each of the sites and are presented in Table 1.

At the atmospheric sites, air was sampled during the period between May 1947 and November 1950. Samples were taken continuously, by aspiration methods, using distilled water as an absorbent to collect airborne materials. Analysis of this absorbent water was made three times a year, January to April inclusive (dry season), May to August inclusive (wet season), and September to December inclusive (wet season). Summaries of these analyses showing the constituents of the air considered significant to corrosion, are presented in Table 2.

Sufficient meteorological data were collected at each of the test sites to enable a correlation between these data and data taken at proximate locations by the Panama Canal Company, Section of Hydrography and Meteorology. Earlier reports in this series[1, 2, 3] contain these data with daily variations in temperature and humidity for a representative week during the wet season and dry season. The dry season is approximately five months long (December to May).

Metals and Methods

Sufficient samples were provided so that ten replicates of each metal were exposed in each environment. This enables the removal of duplicate panels from each location after one, two, four, eight, and sixteen years' exposure. The chemical composition of the wrought iron and structural steels included in this report is presented in Table 3.

Uncoupled samples intended for exposure at the water immersion sites were 9 inches square and ¼ inch thick. Coupled samples were 9 x 9 x ¼ inch plates to which 2 x 9 x ¼ inch strips were bolted. A component view is shown in Figure 1. Before exposure, all were solvent cleaned and vapor degreased in trichloroethylene. They were then pickled at 170 F ± 5 F in 10-percent sulfuric acid for 10 minutes, with the exception of the carbon steel and wrought iron samples that were to be exposed with a machined or millscale surface.

Following pickling, the panels were rinsed in water and brushed with a vegetable fiber brush. They were then immersed for ½ to 1 hour in 170 F water to expel absorbed hydrogen. The test pieces were then dried in an oven at 160 F before being placed in a desiccator for

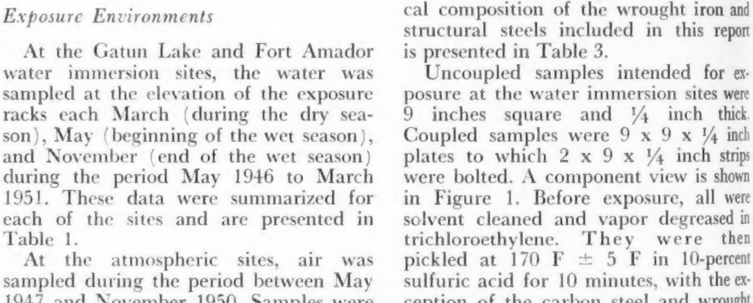

Figure 1—Underwater bimetallic couple sample prior to assembly.

★ Submitted for publication December 21, 1959. A paper presented at the 16th Annual Conference, National Association of Corrosion Engineers, Dallas, Texas, March 14-18, 1960.

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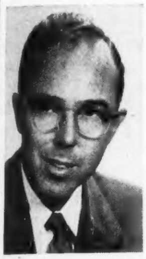
He also has held offices in the American Society for Testing Materials. Other technical societies of which he is a member are the Federation of Paint and Varnish Production Clubs, the American Institute of Chemists, Washington Academy of Sciences, and Research Society of America (NRL Branch). He is presently an executive in the chemistry branch of the U. S. Naval Research Laboratory and was educated at the University of North Carolina with BS, MS and PhD degrees.



CHARLES R. SOUTHWELL is a Materials Engineer for the Naval Research Laboratory. Since joining the organization in 1954 he has been engaged in the study of deterioration of metals, woods, and protective coatings in tropical environments. From 1950 to 1954 he was Engineer-in-Charge of concrete and protective coatings for the construction of the International Falcon Dam, and prior to 1950 was a Materials Engineer for the Panama Canal Company doing investigative work pertaining to concrete, metals, and protective coatings for use in design of a sea-level canal at Panama. He attended St. Mary's University of Texas, and is a member of NACE.

B. W. FORGESON is in charge of the tropical exposure and laboratory facilities in the Panama Canal Zone for the Naval Research Laboratory. He has been in the employ of the laboratory since 1953, during which time he has been actively engaged in the study of corrosion, protective coatings and the biological deterioration of materials. From 1940 until 1952, he worked for the Special Engineering Division of the Panama Canal as a materials engineer assigned to various research problems and laboratory work concerned with a proposed construction of the third set of locks and the sea level canal. He attended Pennsylvania State University and is a member of NACE.

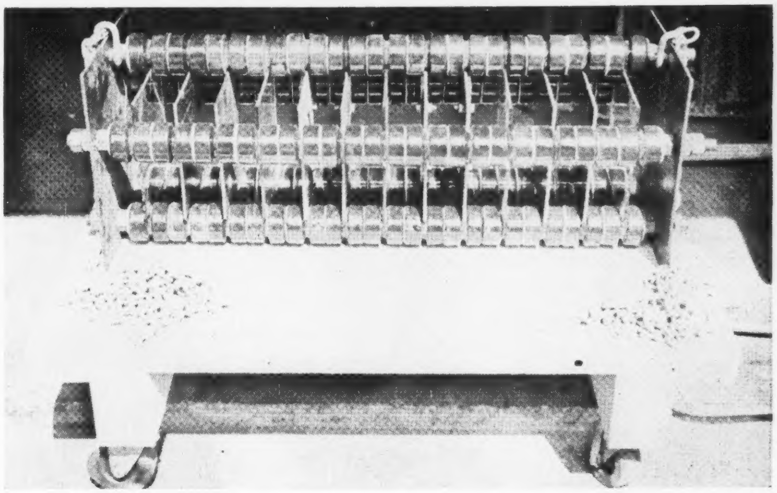


Figure 2—Typical immersion rack with specimens and glass barriers in place.

cooling prior to initial weighing. Each sample was accurately weighed, measured, inspected, and photographed prior to being installed in its rack, as shown in Figure 2. The panels were in contact with ceramic insulators only and were oriented such that the direction of rolling was horizontal.

Each rack contained four sets of duplicate specimens with glass barriers between each set and between the terminal specimens and the ends of the racks. This arrangement provided insulation against stray electrical currents. The racks were located so that no two racks containing significantly dissimilar metals would be in proximate locations. Each pier position supported an upper and lower rack. At the Fort Amador pier in Pacific sea water, the two levels were 14 ft. apart; the lower rack was located 14 ft below mean tide for continuous immersion, and the top rack at mean tide elevation, several feet above low tide. At the fresh water exposure site in Gatun Lake, the two racks were submerged continuously and located at elevations of 78.3 and 74.8 ft above sea level; the variation in lake-surface elevation was between 80 and 85 ft.

The samples exposed to the tropical atmospheres measured 4 x 8 x 1/16 inches. Prior to exposure, all of the atmospheric samples were processed in the same mannor as those for the immersion tests. They were then exposed to the atmosphere at Miraflores and Cristobal, Canal Zone, mounted on stainless steel racks with the specimens held at an angle of 30 degrees from the horizontal. The exposure area at Miraflores represents an inland tropical condition without jungle shade, and is approximately five miles inland from the Pacific entrance to the Canal. The prevailing winds at the Miraflores site are from the inland side and north. The racks are on the ground and face south.

The Cristobal test area is in a tropical marine atmosphere, as the site is located approximately 300 ft from the Caribbean coast and the prevailing winds are from the sea. The racks are situated on the roof of the Washington Hotel, 55 ft above sea level, and face north toward the sea.

Upon removal from exposure, the immersed panels were cleaned of marine growth and heavy corrosion product at the exposure sites. The panels from all locations were chemically cleaned at the laboratory by immersion in 10-percent sulfuric acid with 1-percent quinoline ethiodide inhibitor. Additional mechanical cleaning was employed when necessary. The cleaning loss did not exceed 40 mg per sq dm on any of the samples. These losses were not large enough to warrant correction. Cleaned samples were weighed, measured, inspected, and photographed. Pit depths were referred to the original surface of the metals, either by measurement from an uncorroded surface or by calculation using the original and final average measured thickness of the sample. The average of the twenty deepest pits represents the average of the five deepest pits measured on each side of duplicate specimens (an area of 2.25 sq ft for the immersion samples and 0.89 sq ft for the atmospheric samples). The methods of exposure and evaluation were considered in more detail in the first report of this series[1].

Underwater Corrosion Results

A comprehensive summary of the results of corrosion after one, two, four, and eight years' exposure is presented in Table 4. In the case of the immersion samples, average penetration is reported. For the atmospheric samples, the average reduction in thickness is listed. Both of these values are calculated from the average weight loss of duplicate panels, which is presented in the table as average g/dm^2. The values of penetration and reduction in thickness indicate the general progression of corrosion over the entire surface of the panel. Accelerated pitting is considered more significant than average weight loss in many types of structures, therefore the average pitting attack and the deepest penetration are recorded in this same table. Pitting factor is included because of its general acceptance and utility in evaluating corrosion damage.

Structures of wrought iron have, in some instances, been exceptionally resistant to underwater corrosion over periods of many years. Yet, corrosion investigators have been unable to detect this same durability in relatively short-

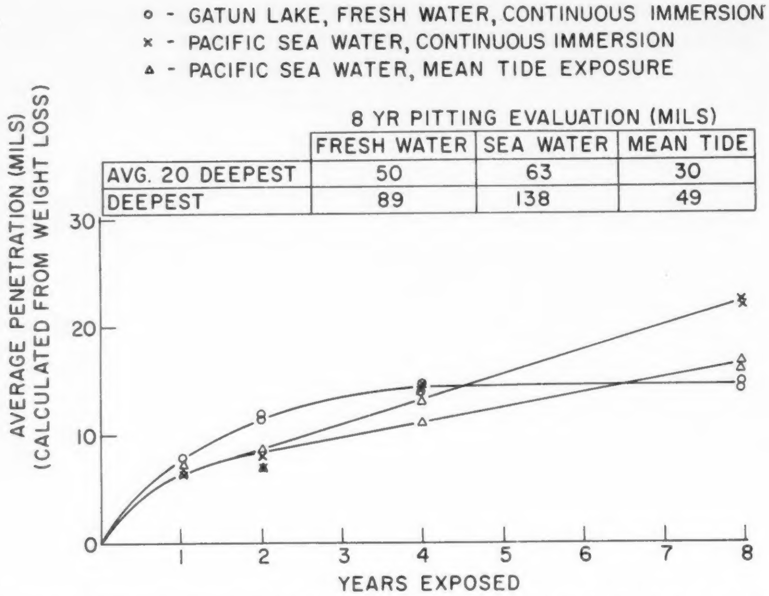


Figure 3—Relative corrosion of wrought iron in fresh water, in sea water, and at mean tide, in the tropical waters of the Panama Canal Zone (machined surfaces).

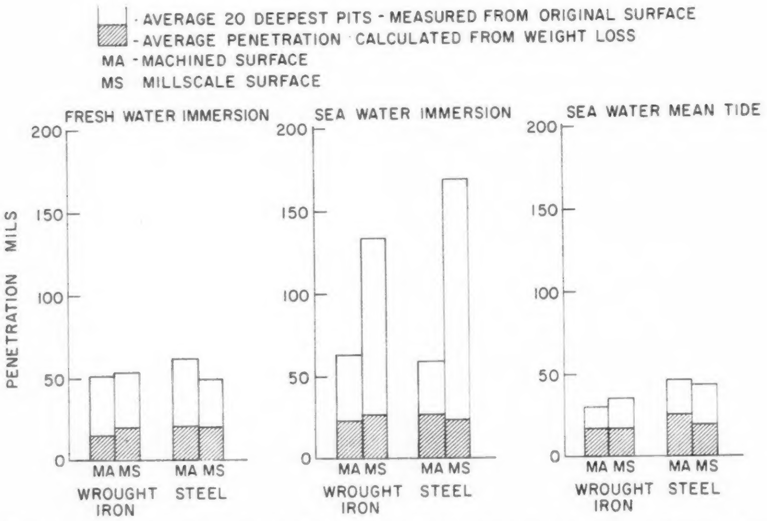


Figure 4—Comparison of the effect of millscale and machined surfaces on the corrosion of wrought iron and unalloyed low-carbon steel exposed for eight years in the tropical waters of the Panama Canal Zone.

term controlled experiments. It is conceivable, then, that wrought iron is much more sensitive to variable exposure environments than is structural steel and that chance favorable environmental conditions were responsible for the extended durability of the enduring structures. In this investigation three different underwater corrosion environments have been evaluated. Figure 3 shows the relative corrosion rates of wrought iron in the three underwater exposures for a period of eight years.

It can be observed from these curves that wrought iron continuously immersed in sea water suffered the greatest corrosion damage for the eight-year period; it lost 54 percent more weight than the fresh water immersion. Wrought iron in all three underwater environments was, by the eighth year, corroding linearly with time; but the rates of corrosion at eight years were considerably different for the three conditions. Measured by the slope of the curves at eight years, the corrosion rates were 2.00 mils per year in sea water, 1.10 mils per year at mean tide, and only 0.07 mil per year in fresh water. The fresh water results are of particular interest. In this environment the initial rate of weight loss was higher than for either the sea water or mean tide and the total loss continued higher through the first four years of exposure; however, by the end of eight years corrosion in fresh water had practically ceased. It appears that this might be one of the favorable environments for wrought iron and a wrought iron structure so exposed would, after initial high rate of corrosion, build up a protective film that, if not disturbed, could provide a very long service life. The sea water mean tide and sea water continuous immersion curves do not show this trend but, rather, predict a continued and uniform loss in weight of wrought iron for all time intervals after the first year of exposure.

Pitting penetration values for eight years' exposure, also presented in Figure 3, show that the samples continuously immersed in sea water were the most severely pitted, followed next by the fresh water samples; the lowest pitting was found in the mean tide specimens.

Effect of Surface Condition

The accelerating effect of millscale on the pitting of steel immersed in

TABLE 1—Summary of Individual Analyses of Water Samples Obtained at the Immersion Test Sites

Constituent or Property Determined	Fresh Water, Gatun Lake at Gatun			Sea Water, Pacific Ocean at Fort Amador					
				Upper Rack Level Elevation 0.0 Ft.			Lower Rack Level Elevation —14.0 Ft.		
	Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
Electrical Conductivity (mhos x 10^{-3} at 81 F)	0.12	0.091	0.11	51.7	21.3	42.2	51.7	35.4	45.4
Total Dissolved Solids (ppm)	165	69	113	42,776	22,613	35,832	41,480	26,390	35,735
Total Suspended Solids (ppm)	23	0.0	7.6	220	0	64	173	0	49
Turbidity (ppm)	<5	<5	<5	20	<5	<5	25	<5	<5
Oxygen Saturation (percent)	98	78	90	105	62	90	103	64	87
Oxygen Consumed (ppm)	2.4	0.7	1.4	2.5	0.6	1.6	2.6	0.4	1.6
Biochemical Oxygen Demand (ppm)	2.2	0.1	1.0	3.4	0.2	1.6	2.3	0.0	1.5
pH (colorimetric)	8.0	6.9	7.5	8.4	7.8	8.2	8.4	7.8	8.1
Organic and Volatile Matter (ppm)	65	6.6	34	10,379	2,150	6,226	10,632	2,759	6,236
Sulfate (ppm)	7.2	0.0	2.6	3,240	1,590	3,177	3,177	1,837	2,473
Chloride (ppm)	12.5	0.0	7.0	20,098	11,300	17,415	19,949	10,379	17,357
Nitrate (ppm)	Trace	0.0	Trace	0.01	0.00	Trace	0.01	0.00	Trace

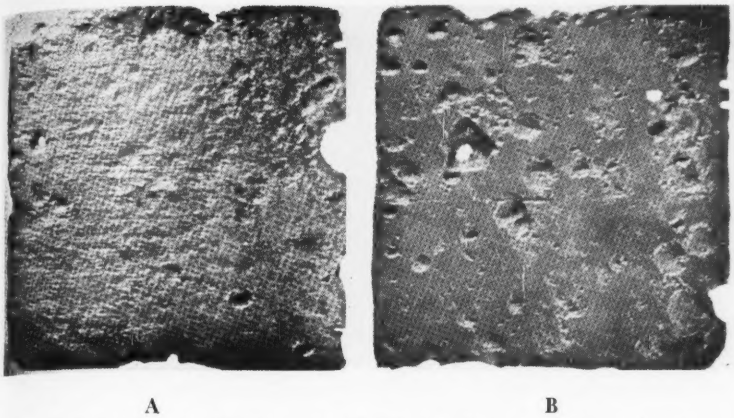


Figure 5—Wrought iron and mild steel exposed with millscale surfaces in sea water for eight years.

sea water is well known and has been treated quantitatively in a previous report of this series.[3] Much less is known about the effect of wrought iron millscale. J. L. Wilson[7] states that the millscale on wrought iron, being less adherent than steel millscale, is soon removed on exposure and the effect on pitting from the cathodic millscale is much less intense than in the case of steel. In these tropical exposure studies wrought iron and steel were exposed with both millscale and machined surfaces.

Figure 4 compares the effect of millscale on the pitting and average penetration of these two metals in the tropical underwater environments. Figure 5 is a photograph of one of the millscale panels of wrought iron and one of steel after eight years' continuous immersion in tropical sea water.

Examination of these figures reveals that in continuous sea water immersion wrought iron with millscale was somewhat less severely pitted than the millscaled steel although penetration had occurred on both metals (3 perforations in the two ¼-inch-thick 9 x 9 inch steel panels and 1 in the similar wrought iron test pieces). However, the average of the 20 deepest pits as shown in Figure 4, was about 20 percent less for millscale wrought iron than for millscale steel. The same figure also shows that there was no significant effect from the millscale in either fresh water or in sea water at mean tide.

Comparison with Structural Steel

Substitution for wrought iron, a well-established material of construction, can be justified only by a superior and/or more economical product. That structural steel can be substituted on the basis of both economy and mechanical properties is a matter of record. Whether steel can claim, also, an equality or superiority on the basis of corrosion resistance has been the subject of long debate. At present, no steel structures of comparable age exist for comparison with the durable wrought iron structures. Most of the data which have been reported for temperate climates reveal no practical advantage for either material in resistance to underwater corrosion. Speller[8] has compiled the results of a number of evaluations in sea water and found generally an insignificant difference between steel and wrought iron. But tests made by J. N. Friend[9] in Ceylon for a 15-year period do indicate lower corrosion losses for wrought iron than for steel over the long term in tropical waters. The questions still unsettled concerning these corrosion differences definitely warranted the investigation of the comparative corrosion of modern-process steel and new control-blended Aston-process wrought iron in the Canal Zone tropical exposure tests.

The mild unalloyed structural steel previously reported[3] is selected here as the reference metal for comparison with wrought iron in the underwater tests. Results of eight years' exposure of wrought iron are compared with the unalloyed structural steel in Figure 6. The time-corrosion curves show the progression of penetration as measured by weight loss for each condition of exposure; the respective pitting penetrations are tabulated with each curve.

The results in fresh water show a widening difference in weight loss that will probably increasingly favor the wrought iron. The comparative rates of corrosion at eight years, as indicated by the slope of the curves at this time, are 1.50 mils per year for steel and 0.07 per year for wrought iron. There was no marked difference in the pitting of the two metals in this environment.

The sea water immersion results indicate that weight loss from corrosion was almost equal for the first four years of exposure, but by eight years the weight loss of the mild structural steel exceeded that of wrought iron by 22 percent. The small differences in pitting penetration of the two metals in this environment were unimportant. It is obvious that

TABLE 2—Summary of Individual Analyses of Air Samples Obtained at the Atmospheric Test Sites

Constituent (determined in mg per 100 cu. ft.)	Cristobal Test Site			Miraflores Test Site		
	Maximum	Minimum	Average	Maximum	Minimum	Average
Total Dissolved Solids	5.48	0.30	1.70	2.58	0.15	0.86
Organic and Volatile Matter	1.72	0.16	0.74	0.69	0.11	0.34
Sulfate	0.64	0.030	0.20	1.13	0.011	0.25
Chloride	0.42	0.035	0.23	0.16	0.013	0.055
Nitrate	0.11	0.00	0.031	0.12	0.00	0.040

TABLE 3—Chemical Composition of Wrought Iron and Structural Steels Evaluated for Tropical Exposures

Metal	Type	Specification	Composition (Percent)								
			C	Mn	P	S	Si	Cr	Ni	Cu	Mo
A	Wrought Iron, Aston-Process	(Atmospheric) ASTM A162-39	0.02	0.024	0.117	0.015	0.095	0.01	0.007	0.018	...
		(Immersion) ASTM A42-39	0.04	0.038	0.141	0.018	0.098	(Trace)	0.006	0.020	...
B	Steel, Unalloyed, Low-Carbon	QQ-S-741 Type II Grade A, Class 1	0.24	0.48	0.040	0.027	0.008	0.03	0.051	0.080	...
C	Steel, Low-Alloy	Proprietary Cu-Ni	0.13	0.41	0.007	0.026	0.048	......	1.70	0.90	...
D	Steel, Low-Alloy	Proprietary Cu-Cr-Si	0.12	0.41	0.084	0.026	0.50	0.60	0.63	0.43	...
E	Steel, Low-Alloy	Proprietary Cu-Ni-Mn-Mo	0.09	0.73	0.065	0.018	0.067	0.03	0.82	0.59	0.19
F	Steel, Low-Alloy	Proprietary Cr-Ni-Mn	0.11	0.54	0.086	0.029	0.18	0.50	0.40	0.57	...

TABLE 4—Comprehensive Corrosion Evaluation of Wrought Iron and Five Structural Steels Exposed to Tropical Environments in the Panama Canal Zone

Type Metal	Exposure	Weight Loss (g/dm²)				Average Penetration (mils)*			
		1 Yr.	2 Yr.	4 Yr.	8 Yr.	1 Yr.	2 Yr.	4 Yr.	8 Yr.
Wrought Iron, Millscale A	Lake Water Immersion	14.60	22.36	29.48	37.22	7.4	11.3	15.0	18.9
	Sea Water Immersion	12.45	18.41	29.85	51.45	6.3	9.3	15.1	26.1
	Sea Water Mean Tide	11.98	12.26	16.10	33.90	6.1	6.2	8.2	17.2
Wrought Iron, Machined A	Lake Water Immersion	14.99	23.12	28.27	28.85	7.6	11.7	14.3	14.6
	Sea Water Immersion	12.74	15.14	28.22	43.81	6.5	7.7	14.3	22.2
	Sea Water Mean Tide	14.30	15.62	23.93	32.31	7.3	7.9	12.1	16.4
Structural Steel, Millscale B	Lake Water Immersion	12.58	18.99	27.23	37.67	6.3	9.6	13.7	18.9
	Sea Water Immersion	8.38	15.53	30.09	46.49	4.2	7.8	15.1	23.4
	Sea Water Mean Tide	18.39	22.48	26.28	36.85	9.3	11.3	13.2	18.5
Structural Steel, Machined B	Lake Water Immersion	15.02	23.21	31.75	40.25	7.5	11.7	16.0	20.2
	Sea Water Immersion	11.01	18.04	29.81	53.93	5.5	9.1	15.0	27.1
	Sea Water Mean Tide	21.05	21.73	30.51	49.52	10.6	10.9	15.3	24.9
Wrought Iron, Pickled A	Seashore	5.41	7.63	13.69	21.76	......	......	......	......
	Inland	3.35	2.39	9.35	13.56	......	......	......	......
Low-Alloy Steel, Pickled C	Seashore	3.43	4.67	6.08	10.01	......	......	......	......
	Inland	2.23	3.43	4.94	6.84	......	......	......	......
Low-Alloy Steel, Pickled D	Seashore	3.38	4.45	6.18	10.15	......	......	......	......
	Inland	1.96	2.96	4.26	5.77	......	......	......	......
Low-Alloy Steel, Pickled E	Seashore	3.43	4.70	5.94	9.74	......	......	......	......
	Inland	2.09	3.51	5.08	6.86	......	......	......	......
Low-Alloy Steel, Pickled F	Seashore	3.33	4.46	5.58	8.98	......	......	......	......
	Inland	2.29	3.46	4.80	6.36	......	......	......	......

* Calculated from weight loss and specific gravity.

short-term tests would have been of little value for evaluating the difference between the wrought iron and steel continuously immersed in sea water.

At the mean tide location the wrought iron showed appreciably less weight loss at all exposure periods and the slope of the curves at eight years indicates that with additional exposure time the curves will continue to diverge and probably an even more favorable position for wrought iron would be disclosed. Pitting penetration after eight years at mean tide was much less for the wrought iron than for the unalloyed structural steel.

During immersion the Aston-process wrought iron apparently builds up its resistance to corrosion very slowly. Examination of the data at four years or less actually would have shown very little advantage for this material. The trend of the curves between four and eight years does show some advantage for wrought iron and if this trend continues for the maximum exposure period of sixteen years it would help to explain why wrought iron has gained its reputation for corrosion durability.

Galvanic Corrosion Effects of Coupling with Steel

The immersion in a conductive electrolyte of dissimilar metals, coupled so that the electrical resistance between them is low, provides the necessary conditions for galvanic corrosion of the anodic member of the couple. Complications arise from the fact that the nobility of the metals will arrange in different orders for different electrolytes. Thus the anodic member of a couple of metals close together in the galvanic series could, on exposure to a different underwater environment, change and become the cathode. The situation is complicated further in natural waters by the effects of organism attachment and protective corrosion product buildup, both of which are functions of time. Possible slight chemical variations in materials with the same general name such as wrought iron and structural steel may also change their position in the galvanic series.

In this long-term investigation a large number of dissimilar metals combinations have been submerged and exposed to the atmosphere. Among the combinations under study were couples of wrought iron and low-carbon mild structural steel, immersed for a period of eight years in Gatun Lake and in the Pacific Ocean. The submerged specimens were 9 x 9 x ¼ inch plates to which were bolted 2 x 9 x ¼ inch strips. The combinations considered here consist of steel strips bolted to wrought iron plates, wrought iron strips on steel plates, and, for purposes of comparison, steel strips on steel plates.

Since steel and wrought iron are close together in the galvanic series, little effect on the larger plates from the smaller area strips was expected or found. The galvanic effect on the strips, however, was appreciable in sea water and was measurable even in fresh water. These strip weight losses are plotted for the one-, two-, four-, and eight-year exposures in sea and fresh water (Figure 7). Examination of these curves, which relate weight loss to time of exposure, shows the wrought iron to be anodic to the mild structural steel for these conditions of exposure. Although normal wrought iron corrosion has been shown to be somewhat less than steel corrosion for these two exposure conditions (Figure 6), the wrought iron strips, when coupled to the steel plates, were more heavily corroded for all exposure periods than were the steel strips attached to wrought iron plates.

The fresh water studies, while insignificant quantitatively, do show this same tendency. Even though the lake water is a poor electrolytic conductor the same relative anode-cathode relation was found as developed in sea water. The portion of Figure 7 showing the sea water results reveals that the difference here is of quantitative significance with the wrought iron on steel losing 20 percent of its total weight in eight years while a similar steel strip on a wrought iron plate lost only 8 percent of its total weight. Comparatively, the normal corrosion of these strips can be judged by the loss of a steel strip on a steel plate of identical composition (cut from same plate). Strips so coupled showed 13 percent weight loss after eight years.

The normal corrosion of a wrought iron strip, although not measured under these conditions, can be estimated by reference to Figure 6, which shows the corrosion of wrought iron vs steel when exposed as simple plates. From this, the normal corrosion of a wrought iron strip can be assumed to be somewhat less than 13 percent, roughly around 11 percent. Thus it is shown directly that the steel strip was protected by attachment to the wrought iron plate and this protection reduced its normal eight-year weight loss by 34 percent. The corrosion of the wrought iron strip was accelerated by galvanic corrosion and after eight years it had lost approximately 82 percent more weight than it would have normally, and 138 percent more than a steel strip coupled to a wrought iron plate.

The direction of current flow in these galvanic-couple tests was not expected. LaQue in his excellent qualitative guide chart, "Sea Water Corrosion of Galvanic Couples,"[10] gives the opposite cathode-anode relation for wrought iron and steel. Speller, in the 1935 edition of his book, "Corrosion: Causes and Prevention,"[8] cites the exposure of mixed wrought iron and mild steel pipe and concludes that there is practically no difference in the

TABLE 4 (Continued)

Average Reduction Thickness (mils)*				Average 20 Deepest Pits (mils)**				Deepest Pit (mils)**				Pitting Factor***			
1 Yr.	2 Yr.	4 Yr.	8 Yr.	1 Yr.	2 Yr.	4 Yr.	8 Yr.	1 Yr.	2 Yr.	4 Yr.	8 Yr.	1 Yr.	2 Yr.	4 Yr.	8 Yr.
....	....	....	....	18 45 18(19)	38 69 —(0)	39 61 —(0)	53 133 35	23 73 23	45 101	61 168	80 251(p) 41	3 12 4	4 11 1	4 11 1	4 10 2
....	....	....	....	26 31 16(16)	41 51 —(0)	48 72 —(0)	50 63 30	32 47 22	51 90	66 128	89 138 49	4 7 3	4 12 1	5 9 1	6 6 3
....	....	....	....	29 55 16	43 77 18	34 108 23	48 168 43	40 104 21	67 113 30	51 158 40	74 263(p) 75	6 25 2	7 14 3	4 10 3	4 11 4
....	....	....	....	22 38 21(18)	37 61 21(15)	53 57 35(15)	61 58 58	26 64 40	47 157 29	62 118 57	88 157 124	3 12 4	4 17 3	4 8 4	4 6 5
5.5 3.4	7.8 5.7	13.9 9.5	22.1 13.8	12 6(8)	14 9	5 12	29 19	21 9	23 14	7 15	61(p) 28	8 5	6 5	1 3	5 4
3.5 2.3	4.7 3.5	6.2 5.0	10.1 6.9	6 —(0)	7 4	8 6	12 11	10	10 6	11 8	17 14	6 1	4 3	3 2	3 4
3.4 2.0	4.5 3.0	6.2 4.3	10.2 5.8	10 —(0)	8 6	8 7	12 10	18	16 7	11 8	28 17	10 1	7 5	4 4	5 6
3.5 2.2	4.8 3.6	6.0 5.1	9.8 6.9	8 —(0)	7 5(10)	5 7	12 12	14	12 8	6 9	24 16	8 1	5 5	2 4	5 5
3.4 2.3	4.5 3.5	5.6 4.8	9.0 6.4	7(10) —(0)	9 6	6 7	12 13	10	18 8	8 9	22 18	6 1	8 4	3 4	5 6

* Calculated from weight loss and specific gravity.

** Pit depths referred to the original surface of the metal either by measurement from an uncorroded surface or by calculation using the original and final average measured thickness of the sample. Average of 20 deepest pits represents average of the 5 deepest pits measured on each side of duplicate specimens. (Area, 2.25 sq. ft. on immersed specimens, and 0.89 sq. ft. on atmospheric specimens); values in parentheses indicate total number averaged when less than 20 measurable pits. Perforation of plate by deepest pit is indicated by (p).

*** Ratio of the deepest measured penetration to the average calculated penetration.

corrosion of these two metals, even though the mixed pipe constitutes a wrought iron-steel couple.

Atmospheric Corrosion Results

During the first quarter of the 20th century the corrosion of wright iron in natural atmospheres was the subject of much discussion and some experimental work. The interest was keen because the steel age had arrived and steel had replaced wrought iron for many uses; but many engineers, knowing the long-lasting properties in the atmosphere of some of the better made wrought irons, were doubtful that steel would be equally as good in this respect. Many results, notably those of Hudson[11] and Friend,[9] seemed to establish that these hand-puddled European wrought irons were somewhat superior to mild steels in atmospheric corrosion resistance but they also pointed out that differences between various brands of wrought iron were often more significant than differences between wrought iron and mild steel.

Relative Intensities

In these studies the U. S.-manufactured Aston-Byers-process wrought iron as well as several modern U. S.-produced structural steels have been tested at a tropical inland and a tropical marine atmospheric location, the inland site at Miraflores, Canal Zone and the seashore location at Cristobal, Canal Zone.

The difference in corrosion intensity of the tropical inland and tropical seashore atmospheres to wrought iron is shown by the two eight-year corrosion-time curves in Figure 8. These curves indicate that after eight years' exposure wrought iron lost approximately 60 percent more weight at the tropical seashore location than at the tropical inland site.

Comparison with a Group of Low-Alloy Steels

A previous report of this series[2] gave complete exposure results on the ten structural steels. Here, for comparative purposes, a band curve representing results of four proprietary low-alloy steels has been included (Figure 9). In the tropical atmospheres these four steels were among the most corrosion resistant of the ten tested. The variations between the four are very slight as can be seen by the width of the bands, which encompass, in the shaded area, the results of 32 specimens, two for each steel at one, two, four, and eight years.

It can be seen in Figure 9 that the atmospheric corrosion resistance of the wrought iron was not nearly as good as any of the four steels. After eight years' exposure the wrought iron had lost more than twice as much weight in both the tropical marine and tropical inland atmospheres as any of the low-alloy steels.

Eight-year pitting penetration (Table 4) also is shown to be greater on the wrought iron than on the steel. In the marine environment the two $\frac{1}{16}$-inch-thick wrought iron specimens removed at eight years had both perforated whereas no perforation occurred on any of the four low-alloy steels at eight years; the deepest penetration on any surface of the steels was less than $\frac{1}{32}$-inch deep.

Conclusions

1. Eight-year immersion studies of a modern controlled-process wrought iron, in the tropical waters of Panama, disclose that the iron is most heavily corroded when continuously immersed in sea water and that weight losses in continuous fresh water immersion and at sea water mean tide are approximately equal. Pitting penetration is lowest at mean tide. The data further reveal that at least four years' exposure is required to reach a condition of linear relationship between corrosion and time. The slopes of the curves at eight years suggest that for longer periods of exposure greater divergence can be expected with sea water causing increasingly heavy corrosion, mean tide of intermediate amount, and fresh water relatively less.

2. Accelerated pitting penetration from exposure of samples with millscale surfaces is apparent only for continuous immersion in sea water. In this medium, millscale on wrought iron seems to be somewhat less harmful than steel millscale, probably because of the poorer adherence and earlier removal by corrosion.

3. Comparisons of wrought iron and mild structural steel exposed in tropical water show that for the first four years, in both continuous sea water and fresh water immersion, there is practically no difference between the two metals. After eight years the wrought iron weight loss is significantly less than that for steel. At mean tide the wrought iron shows less corrosion damage at all periods of exposure. The curve shapes indicate that even greater differences in favor of wrought iron are probable for longer periods of exposure.

4. Coupling wrought iron and steel in underwater tests discloses that the wrought iron is anodic to the steel in both sea water and fresh water. However, a quantitatively significant galvanic corrosion of wrought iron occurs only for the sea water continuous immersion ex-

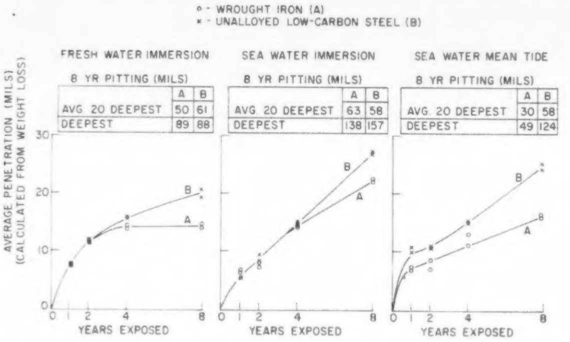


Figure 6—Comparative corrosion of wrought iron and unalloyed low-carbon steel in the tropical waters of the Panama Canal Zone (machined surfaces).

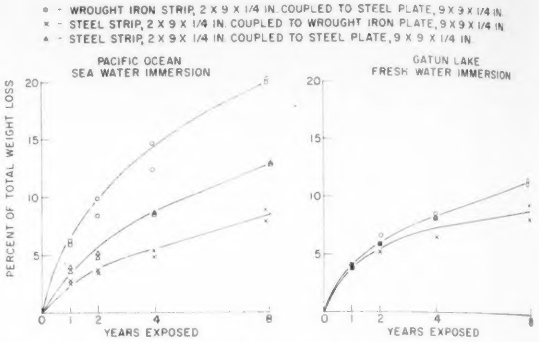


Figure 7—Effect of bimetallic coupling of wrought iron and steel in the tropical waters of the Panama Canal Zone (pickled surfaces).

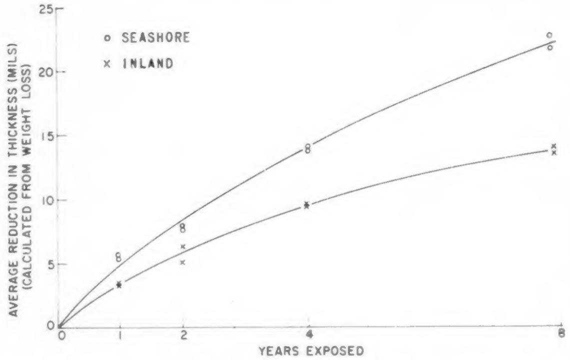


Figure 8—Comparison of tropical atmospheric corrosion of wrought iron at inland and seashore locations in the Panama Canal Zone.

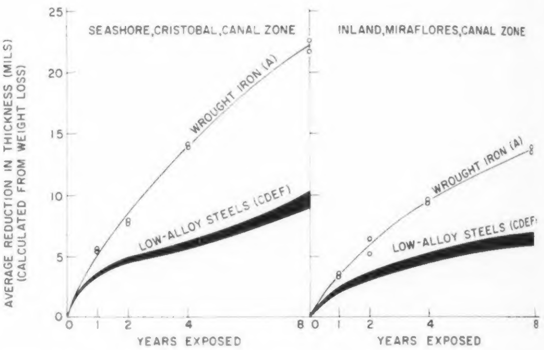


Figure 9—Comparative corrosion of wrought iron and a group of low-alloy steels in tropical atmospheres.

posure. Protection of steel by wrought iron requires a large area of wrought iron in relation to steel and under these conditions the corrosion of steel is reduced by approximately one-half.

5. The effects of tropical inland and tropical marine atmospheres on the corrosion of wrought iron have been evaluated and it was determined that for eight years' exposure the marine atmosphere resulted in 1.6 times more corrosion weight loss.

6. Wrought iron compared to four proprietary low-alloy structural steels in the tropical atmospheric environments, was much more heavily damaged by corrosion than any of the four steels. For both the marine and inland atmospheres the wrought iron had lost more weight at all periods of exposure and by the eighth year, in both environments, the loss was more than double that of any of the steels.

Acknowledgments

The support of the Panama Canal Company and the Engineer Research and Development Laboratories, Fort Belvoir, has been indispensable in the course of this work. The interest of E. M. Browder and George Howard, of these organizations respectively, has been particularly helpful.

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Any discussion of this article not published above will appear in June, 1961 issue.

Use of Alloy Additions to Prevent Intergranular Stress Corrosion Cracking In Aluminum Bronze[*]

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Introduction

THE USE of alpha aluminum bronze alloys in chemical processing systems has often been discouraged because of stress corrosion cracking susceptibility. These alloys have been susceptible to two distinctly different types of stress corrosion cracking. The first type is caused by exposure to ammonia and the second by exposure to steam, hot water, and hot aqueous solutions which do not contain ammonia. Research has produced a model for the mechanism of each type of cracking; the use of this model has resulted in the elimination of the type of stress corrosion cracking caused by steam and hot aqueous solutions not containing ammonia.[1] The approach to the elimination of "steam" cracking has been through the use of small additions to the alloy, which have no detrimental effect on the physical and mechanical properties of the alloy.

The alloy of principal interest in this work is an alpha aluminum bronze of nominal composition, 7 percent aluminum-2 percent iron-91 percent copper. Aside from stress corrosion susceptibility the alloy has very favorable corrosion resistance and strength for use in many applications. It is produced primarily as a wrought alloy and is available in the form of bolting material, rod, pipe, tube, sheet and plate. The composite strength, thermal conductivity, weldability and corrosion resistance of the alloy are such that the alloy is used under conditions of rather high applied and residual fabrication stress. As a result of this, the stress corrosion problem is of primary importance.

Theory

In the model of stress corrosion cracking mechanisms proposed as a result of the previous work,[1] the type of crack path is related to solute or solvent atom segregation at grain boundaries, and to a much finer degree within the crystal lattice itself. The atom concentration resulting from segregation suffers selective attack by the corrosive agent and this local corrosion under tensile stress results in the formation of cracks. This mechanism speculates that the function of stress is primarily a mechanical one, related to the opening of the crack and the rupture of protective films.

The cracks formed by the attack of steam on alpha aluminum bronze are always intergranular.[1] The direct relationship between cracking susceptibility and aluminum content has supported the use of a model of equilibrium grain boundary segregation of aluminum atoms, the

Abstract

The general principles of equilibrium grain boundary segregation are applied to form a theory on the possible elimination of intergranular stress corrosion cracking in alpha aluminum bronze in steam. Various possible alloy additions are discussed in relation to their atom size, solubility, and tendency to react with steam. A theoretical selection of beneficial additions is made. Actual test results on several alloys containing a variety of additions are presented, illustrating good agreement of theory and results. The effects of the additions on transgranular ammonia cracking susceptibility are also discussed. A brief history of the application of laboratory results to field testing and actual application to the product is given. 3.7.2

oxidation of these atoms by the corrosive steam, and the continual rupture of the oxide film at the crack apex because of stress. The elimination of cracking by steam would then depend upon the decrease or elimination of the grain boundary segregation of aluminum atoms. The application of equilibrium segregation theory[2] suggests some possibilities in the elimination of this type of cracking. General points worth consideration are:

1. Grain boundaries can be visualized as being made up of a transition lattice which is highly distorted, so as to produce both dilated and contracted vacant atom sites. Solute atoms larger than the solvent atoms are attracted by dilated vacancies, while atoms smaller than the solvent are attracted by contracted vacancies.[3]

2. The grain boundary segregation tendency in solid solutions is related to the extent of difference between the size of the solute and solvent atoms while the extent of segregation is dependent on the ratio of the solute concentration to its solubility in the lattice.[4]

The general idea behind the cure for intergranular cracking by alloy additions is to produce a situation of substitutional segregation (i.e., an element less likely to be attacked preferentially by corrosive steam is added to the aluminum bronze alloy to occupy grain boundary vacancies which would normally be occupied by aluminum atoms when conditions of equilibrium grain boundary segregation prevail.) This would reduce the aluminum content of the grain boundaries, making the boundaries less susceptible to corrosive attack.

The element added to the alloy for the purpose of reducing the concentration of segregated aluminum atoms at grain boundaries should fulfill the following requirements:

1. The element added must have a high tendency to segregate to the grain boundary. The atom size of the element must therefore be different from that of copper by as much as possible. More specifically, if the segregated alloy additive is to displace aluminum at dilated vacancies in the grain boundaries it should have an atom size equal to or larger than that of aluminum.

2. The element must be soluble in the crystal lattice, since precipitated elements (or phases) would have little if any effect on aluminum grain boundary segregation.

3. The amount added should be significant in relation to the solubility of the element in the crystals, in order that an effective concentration of segregated atoms is produced in the grain boundary. The exact concentration/solubility ratio necessary will vary with each element, since it will depend on segregation tendency (condition No. 1). Therefore, the solubility of the element in the crystal should be quite limited and preferably decrease with temperature if small additions are to be effective.

4. The added element must have a relatively low tendency to react with the corrosive in question (in this case—steam).

Table 1 contains a list of common ele-

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[*] Submitted for publication January 4, 1960.

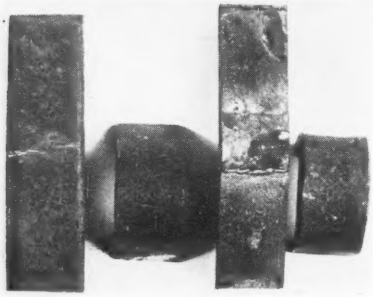

Figure 1—Typical laboratory stress corrosion tests on sheet and weldments of 7 percent Al-2.2 percent Fe, balance Cu alloys.

ments of various atomic size, along with data for their solubility (in copper) and the standard ΔH for the reaction of the element with steam.*

A review of the data indicates that the elements Ag, Ti, Cd, Sn, and Zr should fulfill the basic preferential segregation requirements of conditions 1 through 3. The other elements larger in atomic size than copper are either too soluble to have an adequate segregation tendency when present in small amounts, or are not soluble enough to produce an effective concentration of segregated atoms at the grain boundaries.

The relatively high tendency of Ti and Zr to react with steam, as indicated by the ΔH value, would make these elements just as detrimental as aluminum when segregated at grain boundaries. Thus these elements would not be effective in preventing intergranular cracking.

The elements Ag, Cd, and Sn then remain as potential beneficial additions to the alloy for the prevention of intergranular steam cracking. The use of Cd as an addition to aluminum bronzes for the purpose of reducing intergranular penetration by high temperature steam has previously been favorably evaluated by Davis,[9] so that the evaluation of the effects of Ag and Sn additions are of primary interest in this work.

TABLE 1—Solubility Data for Elements

Element	Atom Size[5]	Solid Solubility[6]		ΔH (K cal/mole of element) $M + XH_2O \rightarrow MO_x + XH_2$[7,8]
		Room Temp.	Maximum	
Be	2.23	0.2%	2.7% at solidus	—77
Se	2.25	0.001%	0.016% at 1500 F	+59
Si	2.32	2.5%	5.5% at 1520 F	—85
As	2.42	6.9%	8% at 1280 F	—14
Cr	2.45	0.004%	0.55% at solidus	—49
Fe	2.46	0.001%	4% at 2000 F	—14
Ni	2.47	100%	100%	+ 1
Cu	2.55	....	....	+ 8
Zn	2.65	38%	39%	—25.5
Al	2.85	8%	9.5% at 1050 F	—103
Ag	2.85	0.2%	8.8% at 1440 F	+25.5
Te	2.85	0%	0%	+38.4
Sb	2.86	1%	11% at 1200 F	+38
Ti	2.87	0.2%	4.3% at 1630 F	—102
Cd	2.98	0.1%	3.7% at 1000 F	—7.2
Sn	3.05	0.5%	15.8% at 1000 F	—22
Zr	3.20	0.3%	1% at 1800 F	—142

TABLE 2—Stress Corrosion Test Results*

Additive	Test Results
Be	All specimens failed within 300 hours.
Se	All specimens failed within 160 hours.
Si	All specimens failed within 900 hours.
As	All specimens failed within 160 hours.**
Cr	All specimens failed within 160 hours.
Ni	All specimens failed within 160 hours.
Ag	No failures in over 3000 hours.
Sb	Hot short—Cracked during rolling.
Ti	All specimens failed within 160 hours.
Sn	No failures in over 3000 hours.
None	All specimens failed within 160 hours.

* On 7% Al—2.2% Fe—balance Cu alloy containing 0.3% of additive, tested under stress of approximately 30,000 psi in 350 F. steam.

** **Note:** Alloy samples containing arsenic were machined on both sides because of moderate surface cracking during rolling.

Experimental Procedure

In order to verify all points of the theory, alpha aluminum bronze alloys of composition 7 percent Al-2.2 percent Fe-Balance Cu with .3 percent of various alloying elements were made up using high purity virgin materials. The additives selected for tests included Be, Se, Si, As, Cr, Ni, Ag, Sb, Ti, and Sn. Slabs 1" thick were cast and hot rolled, using cross rolling techniques, to sheets 3/16" thick x 10" wide x 11" long. Each sheet was then cold rolled about 6 percent, to produce a hardness of 85 to 90 Rockwell B.

Three test strips measuring 5/8" wide and 2 5/8" long were cut from each sheet, with the length of the specimen perpendicular to the final cold rolling direction. This is the orientation which has in the past produced specimens of maximum susceptibility to cracking during the corrosion test.

The stress corrosion tests were performed as described in the preceding articles,[1, 10] using distilled water in the steam autoclaves. The tests on samples which were apparently crack resistant were carried out to over 3000 hours, after which the samples were bent to 180 degrees to open any invisible incipient cracks which may have formed.

Figure 1 shows a set of typical specimens after exposure to 350 F saturated steam. Specimens 1 and 3 (left to right) are parent plate and weldment specimens respectively, which contained no tin and cracked during a 150 hour test. The parent sheet specimen (No. 2) containing .25 percent Sn, and the welded specimen (No. 4) which contained .25 percent Sn in both parent plate and filler metal, showed no signs of cracking when bent 180 degrees after over 3,000 hours of testing. All specimens were stressed to the 30,000 psi level.

Test Results

The results of the tests are shown in Table 2. In order to check the results, the alloys with additives Si, Ag, and Sn were retested, and the data from the original test was verified. The bend tests, as well as a very complete metallographic study, revealed no evidence of incipient intergranular cracking in the specimens containing tin or silver.

Discussion

Intergranular Steam Cracking

The test results appear to support the theory with respect to the beneficial effects of the Sn and Ag additions, and also in the failure of the majority of the other elements to influence intergranular cracking susceptibility. The failure of the alloy containing Ti was in accord with theoretical expectations. It is assumed that the latter condition also will apply to zirconium additions because of the similarity of this element to titanium.

The tests on alloys with additives smaller in atom size than copper were run in an effort to verify the atom size requirements. Of the five small elements tested, Se, As, Cr, and Ni proved to be ineffective, but these results could be explained both on the basis of unfavorable solubility characteristics and the size factor. The addition of both Be and Si to the alloy appear to decrease intergranular cracking susceptibility to some degree, but in either case the apparent immunity to cracking brought about by Sn or Ag additions is not produced. The beneficial effect of the Be and Si additions can be explained using the concept of the simultaneous segregation of the small Be or Si atoms and the large aluminum atoms, occupying contracted and dilated grain boundary vacancies respectively. The effect of the addition of any atoms with favorable solubility and corrosion reaction characteristics, but of smaller atomic size than copper, could then involve:

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* Note: The authors have used the ΔH_{298} as a rough measure of reaction potential, since the actual value of ΔG_{425K} (the free energy change at 300 F) for the particular circumstances involved would be difficult to evaluate with any degree of accuracy. The model of the metallic elements dissolved by the alloy and segregated at the grain boundary complicates the calculations, and estimation of unknown data would probably produce enough error to make further calculations pointless.

1. A dilution effect, in which the silicon (or beryllium) atoms dilute the aluminum rich grain boundary, thereby slowing the rate of aluminum oxidation by the laws of mass action.

2. A grain boundary energy effect, in which the elastic interaction between the contracted grain boundary vacancies and silicon (or beryllium) atoms results in a lowering of the grain boundary energy level, reducing the EMF potential difference between grains and boundaries, thereby reducing the driving force for intergranular corrosion.

It is more difficult to explain just why the silicon addition has an effect that is so much superior to that of the Be addition. The data in Table 1 indicate that Be has both a more favorable limited solubility situation and greater resistance to steam attack than has Si. Perhaps the difference in atomic size, related to the statistical distribution of grain boundary vacancies might have some effect. Or perhaps the data in Table 1, if properly corrected to take into consideration the thermodynamic and solubility situation that actually exists in the alloy, would coincide with the test results.

The effects of the silicon and beryllium additions to aluminum bronze forcefully demonstrate that, even though the theory may be correct, a phenomenological approach to a testing program of this type may produce unexpected but beneficial results. In the application of the theory to other alloy systems in which intergranular cracking could be caused by segregating elements, the recommended approach would involve the testing of a considerable list of likely and borderline additions. A broad testing program is necessary because of the difficulty in applying the data, since the data itself is subject to significant error and can only be used qualitatively.

Effect of Additions on Ammonia Cracking

While the tin and/or silver additions to aluminum bronze eliminate intergranular steam cracking, they have little or no effect on ammonia cracking. This is reasonable because the additions produce a grain boundary effect, and ammonia cracks are normally transgranular in this alloy.

In general, the observations on ammonia cracking in aluminum bronzes coincide with the results obtained by Wilson and his associates in the study of the effect of Si additions to cartridge brasses.[11] A review of this and other cases in which small alloy additions have reduced ammonia cracking susceptibility in copper alloys to any appreciable extent reveals that the effect in each case was similar. The alloy addition tended to eliminate intergranular cracking, but cracking then occurred through the more resistant transgranular paths. This resulted in increased resistance, but not immunity, to ammonia cracking.

There is considerable evidence to support the authors' belief that the use of small alloy additions to eliminate transgranular ammonia cracking in many copper alloys is a very remote possibility.

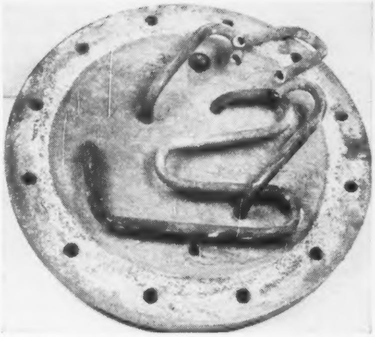

Figure 2—Stressed condenser tube samples after two months of exposure to 350 F steam in an experimental pressure vessel.

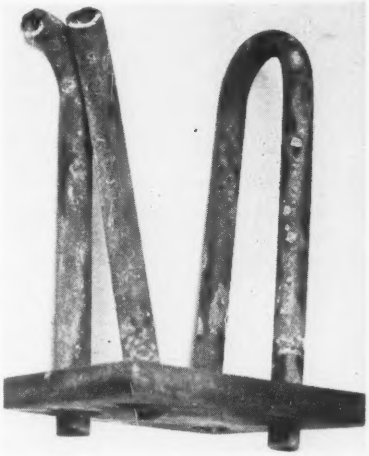

Figure 3—Stress corrosion tests results in fixture stressed alpha aluminum bronze condenser tubes in 350 F steam.

The authors suspect that a rather substantial addition of a high soluble element will be required to influence the ammonia corrosion characteristics of the many small copper rich areas which form crack paths within the crystals. However, if an alloy exists which has no transgranular cracking susceptibility, but is susceptible to intergranular ammonia cracking, the problem could be eliminated by a small addition to the alloy.

Additional Test Work

The laboratory tests on sheet material were followed by tests on weldments of the alloys containing 0.3 percent tin and silver. The filler materials used were a standard 10 percent aluminum-1 percent iron-copper alloy, and the same alloy with a 0.3 percent tin addition, both of which produce duplex (alpha-beta) phase weld deposits. The test specimens were cut from $\frac{1}{4}''$ butt welded plates and machined so that the faces of the welds, with reinforcements intact, were exposed in tension at the center of the specimens.[10] While these weld deposits are relatively resistant to steam cracking and are known to fail only under extreme conditions, the addition of tin to the filler metal produced an entire weldment which was immune to steam cracking. This indicates that the tin addition should also impart steam cracking immunity to cast and wrought alpha-beta aluminum bronzes, an indication which limited testing to date has verified.

Tests on both parent plate and weldment specimens were also conducted using acetic acid solutions, salt and sea water, sulfuric acid, and caustic soda solutions in the laboratory test vessels. The results have been found to be identical to those obtained in steam.

The apparent success of laboratory work led to the construction of experimental pressure vessels of 7 percent aluminum-2 percent iron-.25 percent tin sheet material $\frac{3}{16}''$ thick which was cast and rolled on the production line without special laboratory supervision. The vessels were then tested under simulated operating conditions using tap water, salt water, and acetic acid solution.[12] In addition, field tests were conducted wherein stressed samples were mounted on corrosion racks and inserted into various chemical processing systems. Large corrosion racks including high stressed samples of the tin bearing alloy in plate, weldment, and rod form were exposed to Atlantic marine atmospheres under conditions of constant immersion, alternate (tidal) immersion and shore line spray for a period of two years. All of the tests performed to date have indicated that the alpha aluminum bronze alloy containing tin or silver is immune to intergranular stress corrosion cracking.

Figure 2 shows a set of test cooling tubes which were inserted under stress in the head of one of the test vessels. The tubes were extruded and drawn from 7 percent aluminum-2.2 percent iron-balance copper alloy billets, one of which contained 0.25 percent tin. The tube made from the alloy without tin cracked and began leaking after one week of operation in 350 F steam, while the tube which contained tin proved to be sound after one year of operation. Figure 3 shows samples from the same aluminum bronze tubing materials which were stressed in a fixture and set on a baffle plate within the pressure vessel. The results proved to verify those obtained with the cooling tubes.

The final test, the application of the material to customer requirements has also been completely successful to date. The addition of tin to the alloy has apparently eliminated intergranular stress corrosion cracking failures.[13]

Stress corrosion cracking tests were also conducted on the tin and silver bearing alloys using ammonia vapor and solutions, and the results indicate that the additives have no detectable effect on the prevention of (transgranular) ammonia cracking.

Conclusions

The model of the mechanism of intergranular stress corrosion cracking in alpha aluminum bronze has proved useful in prescribing a cure for the problem by small alloy additions of tin or silver to the alloy. Additions of 0.2 percent to 0.3 percent of these elements to the alloy produce an apparent immunity to intergranular cracking in steam or other oxidizing aqueous acid and caustic vapors. The model also presents a possible explanation for the claims of the Davis patent^9 covering the addition of Cd to these alloys. The alloy additions do not affect the relatively mild susceptibility of the alpha aluminum bronze alloys to transgranular cracking, which occurs in atmospheres containing appreciable amounts of ammonia vapor.

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DISCUSSION

Comments by Alan S. Tetelman, Department of Metallurgy, Yale University, New Haven, Connecticut:

The authors appear to have oversimplified the problem of intergranular corrosion by proposing that the answer to the problem is related only to the size difference between solute and solvent atoms and the segregation that results. While this point is true, because the strain energy of solid solution will be lowered when misfitting atoms concentrate in the boundary, there are two other considerations which should have been mentioned in the general discussion of the problem.

The first relates to the segregation tendency of a ternary addition. The grain boundary is an internal surface, and as such it will have an interfacial energy, which tends to make the boundary unstable and accounts for grain growth at high temperatures. Therefore, if a solid solution contained atoms of the *same size* but of *different surface energies*, the component with the lower surface energy would tend to segregate at the boundary in order to lower the surface energy of the boundary.

It should also be pointed out that boundary segregation, be it the result of size or surface effects, is not the complete answer to the problem, for in no case would one expect segregation to be so complete (because of entropy effects) that no aluminum atoms, for example, are located in the boundary region. One must still consider, on a qualitative basis, the effect that the ternary addition will have on the activity, and hence reactivity, of the element with the highest chemical potential.

This is quite evident in the alpha brasses where catastrophic failures are seldom observed until the concentration of zinc is greater than 10 percent. This fact may be attributed to the large negative deviations from Raoult's Law which exist in the copper-zinc system, and imply that zinc is so strongly bound to copper that it will not have much desire to react with the corroding medium. Therefore, large concentrations of zinc are required so that the "effective" concentration of zinc will be sufficient for a chemical reaction to occur within a reasonable period of time. It may well be that ternary additions lower the activity of the element with the highest chemical potential and hence reduce the amount of attack, in addition to their other feature of preferentially segregating at grain boundaries.

Any discussion of this article not published above will appear in June, 1961 issue.

Laboratory Investigation of Water-Side Scale And Corrosion in the Presence Of High Process-Side Temperatures*

By HERMAN KERST

Abstract

A laboratory method of testing water-side corrosion and scale deposition in the presence of high process side temperatures has been developed. Two types of specimens are used: (1) a hairpin of ¼ inch seamless steel tubing mounted on a pipe plug and inserted in the circulating water system, and (2) a miniature heat exchanger made of ½ inch seamless tubing and standard pipe parts.

In studies on corrosion rates, and on calcium phosphate scale deposition under conditions of 130 F water temperature and 350-395 F hot-side temperatures, it was shown that corrosion rates may be increased up to 8 times over the rates on immersed coupons at 130 F. A possible method of calculating water-side skin temperatures is indicated.

It was shown that the use of polyphosphate treatments, at residual levels high enough to give corrosion protection, leads to the deposition of calcium phosphate scale. The use of chromate in combination treatments reduces the amount of this scale deposited, and also appears to reduce the amount of carbonate scale. 4.6.1

About the Author

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Introduction

A PREVIOUS paper from this laboratory by Denman and Friedman[1] described the use of a small commercial cooling tower for the study of corrosion in circulating cooling water systems. In that paper the results of the use of three types of specimens were discussed: steel coupons, nipples, and NDHA coil testers. It was shown that similar corrosion rate results were given by all three specimens even though the coupons and coil testers were immersed in water whereas the nipples simply carried circulating water. There was no way to measure the effects of heat flux through the specimens. Rice,[2] discussing the use of coupons for corrosion measurements in cooling waters, said: "A final and somewhat obvious limitation of the coupon procedures is their unsuitability to heat transfer and, therefore, their inability to measure the amount of thermally caused deposition."

Several attempts have been made to measure the effects of high process side temperatures on cooling water corrosion and scale. Haering[3] used small wooden cooling towers, and circulated the water over electric immersion heaters. Roger and Dillon[4] in their NACE Technical Committee report suggested the use of a pilot cooling tower of 5000 gallons capacity, and a test heat exchanger with a removable tube bundle which could be replaced for each test. They stated that the water velocity and temperature conditions in this exchanger should correspond to plant conditions as nearly as possible. They depended, however, on coupons and/or test nipples for most of their corrosion data.

Shields, Sorg, and Stutz[5] described a pilot heat exchanger unit which they used in conjunction with small pilot cooling towers and a small commercial tower. This exchanger was a metal specimen in the form of a tube with one end closed, inside a borosilicate jacket. Steam was used on the hot side.

Fisher and Whitney[6] also published several methods for measurement of corrosion rates under heat flux conditions. Their specimens were metal discs. Heat was supplied by the heating unit of a large soldering iron.

An ideal test system for evaluating corrosion and scale treatments in cooling water under high heat flux conditions should have the following characteristics:

1. The specimens should be small enough to be weighed.

2. The system should be constructed so that a wide range of temperatures, flow conditions, and materials of construction can be studied.

3. The specimens should be constructed so that scale deposition can be measured quantitatively.

The type of test described in this paper goes far toward meeting all of these requirements. Two types of specimens are used. One is a hairpin shaped length of ¼ inch seamless steel tubing mounted on a pipe plug by means of compression fittings so that it can be inserted into the flowing stream of a cooling system. Hot fluid is circulated through the tube (Figure 1). These specimens can be used for quantitative measurements of both corrosion and scale.

The second type of specimen is a miniature single tube heat exchanger of ½ inch seamless steel tubing contained in a shell made of standard pipe fittings. Hot fluid is circulated outside of this tube while the water flows inside it (Figure 2). This specimen is used for quantitative scale determinations, and for visual inspection and photographing of corrosion and scale conditions.

Experimental

Preparation and Use of Test Equipment

Figure 1 is a section through the hairpin tube test specimen. The ¼ inch seamless steel tubing has the analysis shown in Table 1.

A length approximately 13″ long of this tubing is bent on a ⅞″ radius to give a hairpin shaped specimen, care being taken not to collapse the tubing. Two holes are drilled in a 1½ inch pipe plug on ⅞″ centers, and tapped for ¼ inch IPT at both ends. Standard brass compression fittings for ¼ inch tubing are used to hold the hairpins in place. On the outside of the plug the connection to a hot oil circulating apparatus can be made with compression fittings and copper tubing, or by standard ¼ inch pipe.

In use, the nuts and sleeves of the compression fittings are assembled on the hairpins and the whole assembly degreased in benzene. From this time on the specimens are touched with the skin as little as possible.

The specimens are sandblasted, acid etched for 30 minutes in 1:3 hydrochloric acid, then thoroughly rinsed with slightly ammoniacal water and wiped dry with a soft cloth. After drying in a desiccator, the specimens are weighed to tenths of a milligram. They are then assembled onto the pipe plug and are ready for insertion into the circulating water system.

Figure 3 is a photograph of a complete assembly. These specimens are screwed into 1½ inch tees in the circulating water piping of the experimental pilot cooling towers previously described.[1] Two are used in each test.

Figure 4 shows the placement in the high temperature portion of the piping system leading to the top of the tower. Hot fluid is piped to the specimens through copper tubing, the usual temperature being 350 F. Ucon 50-HB-28OX* is used as the circulating fluid. The flow of water is toward one specimen, and away from the other. Water flow rates vary from about 1.5 to 2.5 feet per second, and there is considerable turbulence due to the presence of the pipe fittings. The

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★Submitted for publication February 9, 1960. A paper presented at the 16th Annual Conference, National Association of Corrosion Engineers, Dallas, Texas, March 14-18, 1960.

* Union Carbide Chemicals Co.

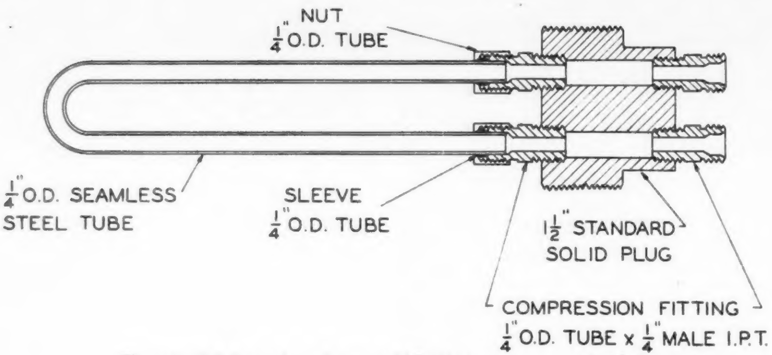
NUT
1/4" O.D. TUBE
1/4" O.D. SEAMLESS STEEL TUBE
SLEEVE
1/4" O.D. TUBE
1 1/2" STANDARD SOLID PLUG
COMPRESSION FITTING
1/4" O.D. TUBE x 1/4" MALE I.P.T.

Figure 1—Hairpin specimen for use in high skin temperature test (section).

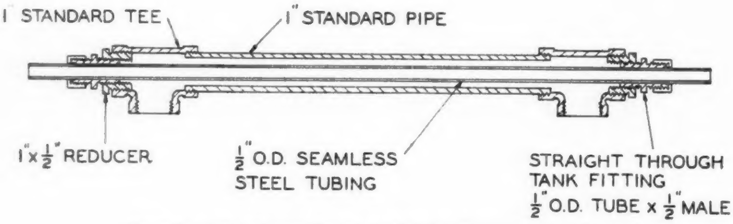
1 STANDARD TEE
1" STANDARD PIPE
1"x1/2" REDUCER
1/2" O.D. SEAMLESS STEEL TUBING
STRAIGHT THROUGH TANK FITTING
1/2" O.D. TUBE x 1/2" MALE I.P.T.

Figure 2—Heat exchanger for use in high skin temperature test (section).

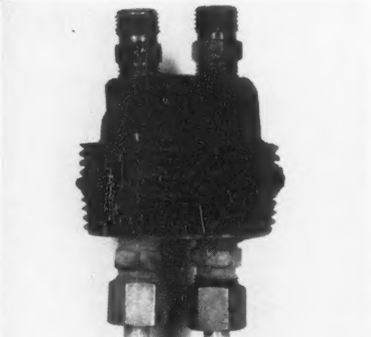

Figure 3—Hairpin specimen for use in high skin temperature test. Shown is the complete assembly ready for insertion in circulating water.

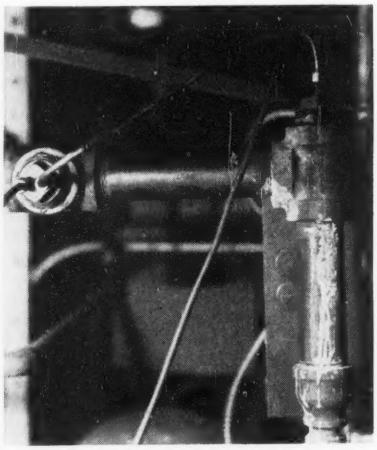

Figure 4—Two hairpin specimens in place in circulating system of laboratory pilot cooling tower.

TABLE 1—Composition of 1/4 inch Seamless Steel Tubing

Constituent	Percent
Carbon	0.07
Phosphorus	0.016
Sulfur	0.030
Manganese	0.53

TABLE 2—Typical Compositions of Circulating Water in Cooling Tower Test Equipment

Constituent	Parts Per Million	
	In Pilot Towers	In SCT Units
Total dissolved solids	1960	1810
Calcium (Ca)	352	278
Magnesium (Mg)	158	80
Bicarbonate (HCO_3)	54	63
Chloride (Cl)	79	95
Sulfate (SO_4)	1170	1000
Silica (SiO_2)	....	1.4
Hardness ($CaCO_3$)	1276	1030
MO alkalinity ($CaCO_3$)	44	52
P alkalinity ($CaCO_3$)	None	None
pH	7.4	7.0

TABLE 3—Composition of 1/2 inch Seamless Steel Tubing

Constituent	Percent
Carbon	0.07
Phosphorus	0.014
Sulfur	0.031
Manganese	0.39

temperature and pH of the water are set for each test, and may vary from one run to another. The circulating water has the analysis shown in Table 2, corresponding to Chicago tap water concentrated about eight times.

In addition to the hairpin specimens, there are 1 inch x 2 inch coupons placed in flow chambers and removed in pairs periodically in order to determine corrosion rates. Also at the end of each run, the deposits in the tower heat exchanger (Bell and Gossett SU43-4 unit with copper tubing) are removed by dissolving in inhibited muriatic acid, and analyzed for type and amount of scale.

At the end of a ten day run the hairpin specimens are removed and photographed before cleaning. Figure 5 shows the typical appearance of the specimens from a blank run. They are then cleaned by immersion in dilute (1:3) inhibited hydrochloric acid for 5 minutes maximum. (The losses of steel from the specimen and brass from the nuts are negligible). The specimens are then rinsed, dried in a desiccator, and weighed to determine the weight loss due to corrosion.

Figure 6 shows the appearance of cleaned specimens. The inhibited acid solution of the scale is made up to 500 ml in a volumetric flask and analyzed for iron, calcium, magnesium, phosphate, sulfate, etc., according to the type of deposit. These figures can be compared with those given by the analysis of the scale in the tower heat exchanger described above.

The miniature heat exchanger type of specimen is shown in section in Figure 2. The shell of the heat exchanger is made of standard pipe fittings. The tube is a 24 inch piece of 1/2 inch seamless steel tubing of the analysis shown in Table 3.

Assembly of the tube into the shell is conveniently made by the use of a straight-through tank compression fitting which allows the tube to go all the way through. In order to approximate the usual conditions in heat exchange equipment, the steel tubing is ordinarily used as received, after solvent washing to remove grease and oil. Each tube should be inspected before use to make sure that the inside is clean and smooth, and free from seams. Tubing of metals other than steel can also be used.

This miniature heat exchanger can be used in various ways to study and measure the effect of high skin temperatures on scale deposition. In these tests hot

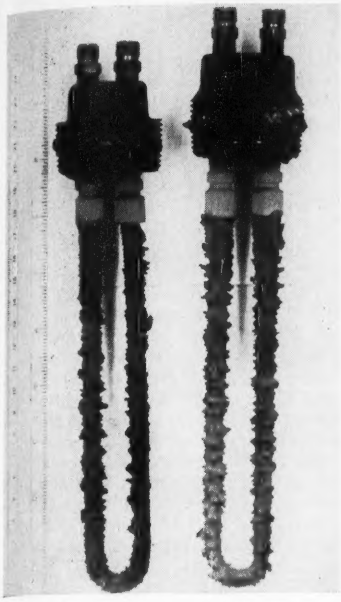

Figure 5—Typical appearance of hairpin specimens and deposited scale after removal from a 10 day blank test at a pH of 7.5. (Before removal of scale).

Ucon was circulated through the shell, and water passed through the tube. Figure 7 shows two of these heat exchangers E in place, being used in conjunction with screening tests on cooling water treatments. The Ucon is heated with a standard electric circulating oil heater A, and pumped by means of a small gear pump B at a rate of about 2 gallons per minute. The temperature of the hot Ucon is measured by a short-stem thermometer C inserted into a tee in the piping. An expansion chamber for excess Ucon D is provided on top. In the figure, Ucon is being circulated to two heat exchangers in parallel at a temperature of 350 F. If the equipment is properly insulated higher temperatures can be obtained.

The water which is circulated through these tubes comes from screening units which are used for preliminary evaluation of cooling water treatments before final testing in the pilot towers. These are called SCT (Simulated Cooling Tower) units, and the analysis of the synthetic water used in them is shown in Table 2. A continuous flow of this water, adjusted for pH and with the treatment added, passes into a stainless steel bucket and overflows to waste. The temperature of the water in the circulating system is controlled by an immersion heater and a regulator.

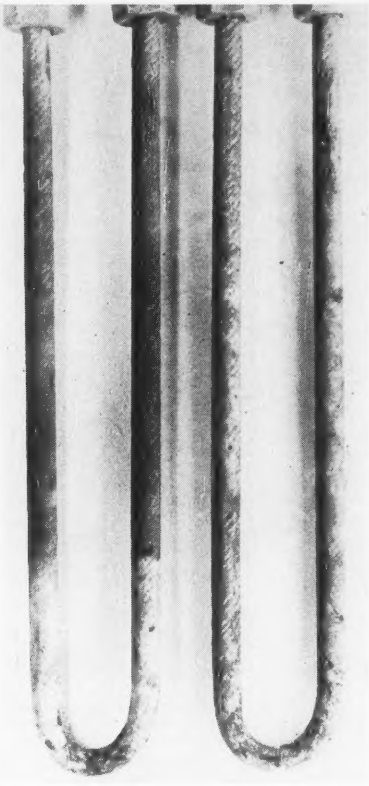

Figure 6—Appearance of hairpin specimens shown in Figure 6 after removal of scale.

The water is pumped through a chemical glass specimen holder (F in Figure 7) containing 1 inch x 2 inch low-carbon, cold-rolled steel coupons. Two of these coupons are taken out each day, cleaned, and weighed in order to study the type of corrosion curve given by the treatment. The same water, passed through the tube of the heat exchanger described above, deposits scale which is typical of the conditions, type of water, and treatment.

The flow rate of the water through the tube is about 3-4 feet per second.

At the end of a ten day test the tubing is removed and two 3 inch lengths are used for scale analysis. The scale is dissolved out with inhibited acid, and the calcium and phosphate determined. Calcium and phosphate are determined when working with deposits which contain mainly these two constituents, and reported as grams of tricalcium phosphate per 24 inch length of tubing. Other analyses are used for studies on other types of scale. Short lengths of the tubing are also split in two lengthwise and the appearance of the scale and corrosion photographed in color.

Reproducibility of results is only fair, but further work with duplicate tests will probably allow determination of the conditions for better precision. At the present time the data are good enough to allow qualitative and semi-quantitative comparisons to be made. For instance, a set of six tests of the same inorganic combination with various supplemental agents gave from 0.34 to 0.66 grams of scale per length of tube, calculated as tricalcium phosphate. Any differences in this group are probably only qualitative. On the other hand, some of the data in the tables of results differ by a factor of five. Where these differences appear to be reasonable in relation to the conditions of the test, they are probably quantitatively significant.

Experimental Results

Hairpin specimens. Table 4 contains the results of hairpin specimen tests in the pilot cooling towers, in comparison with the results obtained from the more conventional specimens. Since this work is just getting underway, and some of the analytical methods are not yet standardized, the results are only preliminary. Table 5 is a spectroscopic analysis of the scale from test B-125. The chromium comes from the treatment, and the manganese from the steel specimens which contain 0.53 percent Mn. The deposit is mainly corrosion products, apparently held in place by a matrix of calcium and possibly iron phosphates.

Heat exchanger specimens. Table 6 shows the results of blank tests run without any corrosion or scale treatment in the SCT units. Since primary concern was over the control of calcium phosphate scales, 2.5 ppm orthophosphate ion was added to the water. At a pH of 7.5 this water has a positive saturation index

TABLE 4—Results of High Skin Temperature Tests with Steel Hairpin Specimens in Pilot Cooling Towers

Test No.	Average Treatment Residual (ppm)	Temperature (°F)		pH of Water	Corrosion Rate at End of 10 Day Test (MPY)		Scale as Grams Ca Plus Mg		Ratio of Corrosion Rates (Hairpins to Coupons)
		Water	Ucon		Coupons	Hairpins	In Tower Heat Exchanger	On Hairpins	
	Na_2CrO_4 12 Na Polyphosphate 5	130	380	7.0	3.0 (4 days)	17.7 (4 days)	....	....	5.9
B-124....................	Blank	130	365	7.5	45	156	....	....	3.5
B-125....................	Na_2CrO_4 35 Na Polyphosphate 3	130	385	7.5	2.1	13.2	22.5	0.005	6.3
B-126....................	Na_2CrO_4 30 Na Polyphosphate 2	130	390	7.5	2.2	18.0	....	....	8.2
B-130....................	Na_2CrO_4 35 Na Polyphosphate 2	130	370	7.5	1.5	6.1	28.1	0.022	4.1

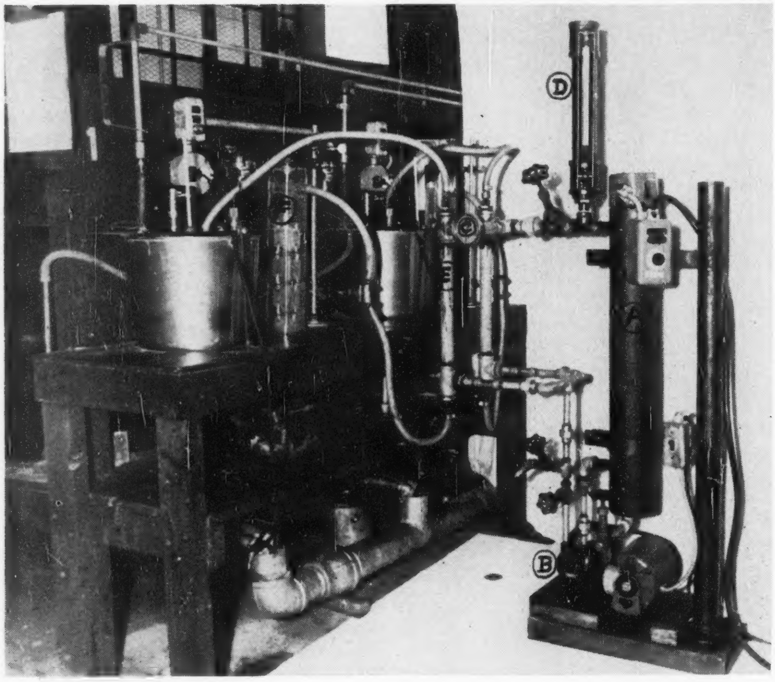

Figure 7—High skin temperature test set up for circulating water and hot fluid through heat exchange specimens. Letter code: A—Electric circulating oil heater; B—Small gear pump; C—short-stem thermometer; D—Expansion chamber; E—Heat exchanger; F—Specimen holder.

as indicated by the tables published by Green and Holmes.[7] The result is a deposit consisting mainly of calcium phosphate plus corrosion products. The results have been reported in terms of tricalcium phosphate. Figure 8 shows the appearance of the split tubing specimens corresponding to the tests in Table 6. The low solids water used in test No. 133 was made up to be equivalent to typical circulating water concentrated about 3-4 times with total dissolved solids less than 1000 ppm.

Table 7 gives the results of several tests with various polyphosphates, and Figure 9 shows the appearance of the corresponding split nipples.

Table 8 shows the results of tests with chromate and polyphosphate-chromate combinations. Figure 10 shows the appearance of the corresponding split nipples.

Table 9 and Figure 11 covers the results of some tests on zinc-chromate combinations.

Discussion of Results

Skin Temperatures and their Effect on Corrosion

The so-called skin temperature at a heat exchange surface, the actual temperature at the interface between the metal and the fluid, has always been an unknown quantity. Attempts have been made to measure this temperature by inserting tiny thermocouples in the metal, as close as possible to the surface. The author is planning to try the same thing, using surface bonded resistance thermometers. However, neither of these procedures can yield anything more than an approximation to the true temperature.

As data on corrosion rates measured by the use of the hairpin specimens accumulates, it becomes possible to try a different approach to the determination of skin temperatures. This is the use of the temperature coefficient of the corrosion reaction itself. This has been reported by Fraser, Ackerman and Sands[8] to be 1.3 for each 10 degree Centigrade rise in temperature. Denman and Friedman[1] reported a figure of 1.5 for this temperature coefficient. Further study of the data on which their finding was based indicates that it was closer to 1.4.

Recent extensive work, using the SCT units for studying the rates of blank corrosion tests under various conditions of temperature and pH have confirmed the average figure of 1.3. In open test equipment the corrosion rate of steel in water drops at high temperatures (around 170 F) due to the decrease in the concentration of dissolved oxygen. In these circulating systems however the water is freshly aerated at all times and the oxygen cannot escape during passage through the heat exchanger. Under these conditions the corrosion rates do not decrease at high temperatures, but, to a first approximation, continue to follow the 1.3 temperature coefficient.

If this temperature coefficient is used and applied to the corrosion rate data in Table 4, the calculated skin temperatures shown in Table 10 are obtained. All of these skin temperatures are above the boiling point of the water, but the water at 130 F is passing over these specimens too fast for boiling to take place. If these skin temperatures at the metal surface are approximately correct, there is a temperature drop of 100 to 150 F across the thin film of scale and liquid between the metal and the body of the water at 130 F. Pending confirmation by other methods of test, the skin temperatures calculated for Table 10 must be considered merely approximations.

The corrosion rate figures in Table 4 and the skin temperatures calculated from them emphasize a very important fact. In refinery operations and in other locations where high process side temperatures exist in heat transfer to cooling water, the corrosion rates of the steel on the water side are many times higher than the rates measured by conventional coupon methods or by resistance probes at the bulk temperature of the water. The final column of Table 4 shows the ratio between the rate on the coupons at 130 F and the rate on the hairpins, even though the hairpins were immersed in the same temperature water. This ratio varies from 3.5 to 8.2 in these few tests, being highest for the highest hot side temperature.

Presumably crevice corrosion, galvanic corrosion, and possibly other types of attack are similarly accelerated. This fact must be kept in mind when translating the results of coupon tests at conventional testing temperatures into design factors.

Effect of High Skin Temperatures on Scale Deposition

This work has been done primarily in the SCT units as shown in Figure 7. Since the deposition of carbonate scales normally can be controlled by the use of small dosages of polyphosphates, primary concern was to study phosphate scales

TABLE 5—Spectroscopic Analysis of Scale Solution from Test B-125 (DK-2 Flame Spectophotometer)

Constituent	Milligrams Per Liter
Calcium	5 ± 1
Sodium	10 ± 1
Chromium	> 20
Iron	200 ± 20
Manganese	2 ± 1

TABLE 6—Results of Blank Tests in SCT Units*

Test No.	pH of Water	Orthophosphate Added (ppm)	CORROSION RATE (MPY)		Scale	Type of Water
			1 Day	10 Days		
3	7.5	2.5	25.4	17.4	0.22 Grams $Ca_3(PO_4)_2$	Standard
107	6.5	2.5	42.4	30.3	0.04 Grams $Ca_3(PO_4)_2$	Standard
133	7.5	2.5	41.2	44.0	0.13 Grams $Ca_3(PO_4)_2$	Low Solids
234	8.0	. . .	21.0	16.7	0.50 Grams $CaCO_4$	Standard

* Water temperature 130 F., Ucon temperature 350 F.

rather than carbonate scales. The use of polyphosphates results in the development of orthophosphate residuals in the cooling water, due to the reversion of the polyphosphate. Under such conditions the problem of carbonate scale deposition has been traded for the problem of phosphate scale deposition. The author's work, therefore, was concerned with calcium phosphate scale formation under high skin temperature conditions using a circulating hot fluid. No investigation has been made yet of this problem under conditions where the heat supplied comes from a condensing vapor at high temperatures.

The results of blank tests (Table 6 and Figure 8) are about as expected. With 2.5 ppm orthophosphate ion added as disodium phosphate, the scale which forms at a pH of 7.5 contains both calcium and phosphate. There is more phosphate than corresponds to the calcium, and it is assumed that iron phosphates or phosphate complexes may be present. The calculation of the amount of scale is based on the calcium content of the scale, and is reported on the basis of total tricalcium phosphate per 24 inches of tubing.

At a pH of 7.5 the water has a positive saturation index for calcium phosphate,[7] and an appreciable weight of material is laid down. Specimen 3 in Figure 8 shows the thick coating of scale which builds up, and there is some appearance of the start of tubercle formation. Specimen 107, at a pH of 6.5 shows an even heavier deposit, but only a small fraction of this consists of calcium containing scale components. Most of the material in fact is corrosion product. Specimen 234 was run at a pH of 8.0, without any orthophosphate. Presumably the calcium is mainly present as carbonate, and there is also much dark corrosion product present. The orthophosphate actually gives some inhibition of corrosion, so that when it is not present serious attack on the metal occurs at these temperatures, even at this high pH. While specimen 133 from a low solids water test shows much less scale deposition, there is incipient tuberculation; the corrosion rate data indicate that this is probably a more corrosive water than the standard.

Table 7 and Figure 9 shows the results of tests with various polyphosphates. The weight of calcium phosphate laid down by these polyphosphates is always greater than in the blanks. But because of the much lower amount of corrosion, the thickness of the deposit is less, as indicated by comparison of the appearance of specimen 18 with that of specimen 3. The deposit on specimen 18 is thin, not very adherent, and has some protective effect. By comparison, that given by the zinc-sodium polyphosphate (specimen 5) is even thinner and much more adherent. The latter deposit has been shown in the laboratory and in the field to be protective. On the other hand, in the presence of pyrophosphate a heavy loose scale is built up, with some local corrosion occurring underneath (specimen 16). Specimens 240 and 241 are from two very similar tests, the only difference being the pH. The test at pH 6.5 gave lower scale and higher corrosion than the one at pH 7.0. The color of the scale at the lower pH was more tan, indicating the presence of more ferric corrosion products. The metal under the scale, however, indicated smooth general corrosion, but that at pH 7.0 showed uneven localized corrosive attack. Finally, specimen 15 shows the use of a lignin derivative with pyrophosphate. Under these temperature conditions the organic does not have any scale control effect, but seems to promote the formation of a hard, adherent, but non-protective deposit.

The use of chromate-polyphosphate combinations for cooling water treatment is widespread. The effect of such treatments on scale depositions at high skin temperatures is shown in Table 8 and Figure 10. Specimen 17 shows the appearance of a chromate treated tube. For purposes of scale determination, 2.5 ppm orthophosphate was added to this water also. The orthophosphate acts with the chromate somewhat as a synergist for corrosion control, and therefore the cor-

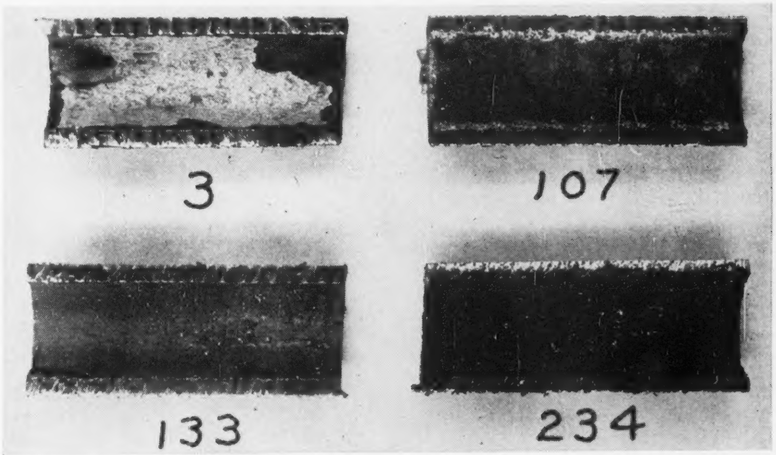

Figure 8—Appearance of inside of heat exchanger tubing specimens corresponding to tests described in Table 6 (Blanks).

TABLE 7—Results of Corrosion and Scale Tests On Polyphosphates in SCT Units*

Test No.	pH of Water	Treatment	Average Polyphosphate Residual (ppm)	CORROSION RATES (MPY)		Scale As Grams $Ca_3(PO_4)_2$
				1 Day	10 Days	
16	7.5	Tetrasodium Pyrophosphate	10	35.8	13.0	0.61
18	7.5	Sod. polyphosphate	30	23.6	7.8	.....
240	6.5	Sod. polyphosphate	25	19.9	10.2	0.34
241	7.0	Sod. polyphosphate	25	17.7	7.4	0.58
5	7.5	Zinc sodium polyphosphate	15	20.6	5.2	0.35
15	7.5	Pyrophosphate plus lignin derivative	10	36.8	10.4	0.82

* Water temperature 130 F; Ucon temperature 350 F; Total fed dosage of treatment 60 ppm; Standard Water (Table 2).

TABLE 8—Results of Corrosion and Scale Tests on Polyphosphate-Chromate Combinations in SCT Units*

Test No.	pH	Na_2CrO_4 Residual (ppm)	Polyphosphate Residual (ppm PO_4)	CORROSION RATES (MPY)		Scale As Grams $Ca_3(PO_4)_2$	Remarks
				1 Day	10 Days		
17	7.5	60	..	3.9	1.0	0.06	2.5 ppm Orthophosphate
10	7.5	22	20	5.9	1.2	0.09	
8	7.5	23	16	6.6	1.1	0.10	....
99	6.5	22	17	11.6	3.0	0.07	....
198	6.5	35	5	8.4	1.6	0.05	....

Water temperature, 130 F; Ucon temperature, 350 F; Total fed dosages, 50—60 ppm; Standard Water (Table 2).

TABLE 9—Results of Corrosion and Scale Tests On Zinc Chromate Treatments in SCT Units*

Test No.	pH of Water	FED DOSAGE (ppm)		CORROSION RATES (MPY)		Scale As Grams $CaCO_3$
		CrO_4	Zn	1 Day	10 Days	
178	7.5	25	25	14.7	1.7	0.03
212	8.0	30	18	9.9	1.3	0.05

* Water temperature, 130 F; Ucon temperature, 350 F; Standard water (Table 2).

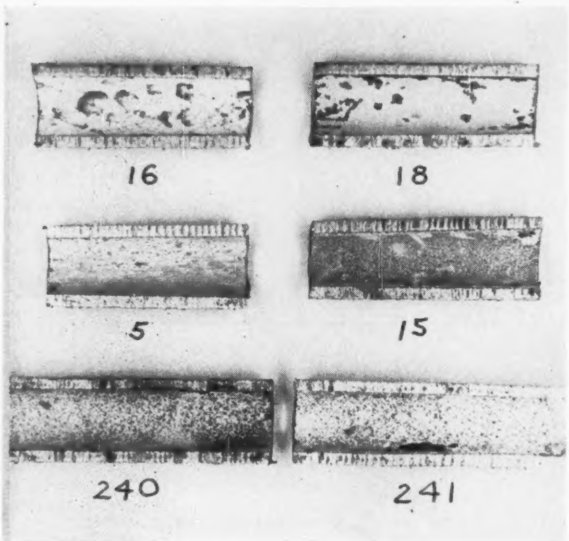

Figure 9—Appearance of inside of heat exchanger tubing specimens corresponding to tests described in Table 7 (Polyphosphates).

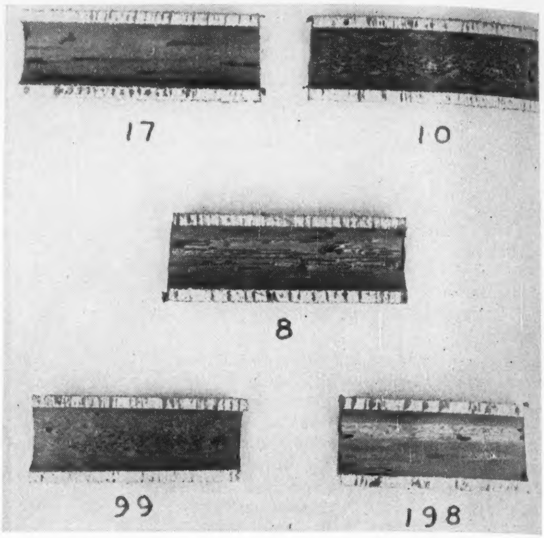

Figure 10—Appearance of inside of heat exchanger tubing specimens corresponding to tests described in Table 8 (Chromate-polyphosphate).

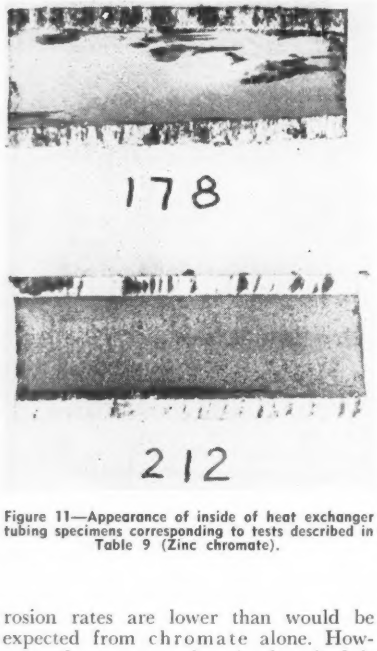

Figure 11—Appearance of inside of heat exchanger tubing specimens corresponding to tests described in Table 9 (Zinc chromate).

rosion rates are lower than would be expected from chromate alone. However, the amount of scale deposited is low, indicating that chromate has some effect in controlling scale under these conditions. This apparently is something which has been known in the field but for which the author has been unable to find literature references. However, specimen 17 shows long tubercles parallel to the direction of flow of the water. Specimens 10 and 8 are from essentially duplicate runs, and show similar results. These specimens show slight local attack which is minimized in specimens 99 and 198 which were tested at a lower pH.

The result of the addition of chromate to a polyphosphate treatment, shown by specimens 10 and 8 in comparison with the specimens in Figure 9 and Table 7, is to reduce the phosphate-based scale deposition. This is a further advantage of this type of treatment, in addition to its control of corrosion. The results of tests 99 and 198 seem to indicate that under these conditions of low pH and high skin temperatures, high chromate-low polyphosphate treatments give better results in controlling corrosion than do high polyphosphate combinations. This finding, however, is complicated by a number of factors, especially the amount of polyphosphate needed to maintain the required residual dosage. Tests at ordinary temperatures have shown better control of local attack by the use of combinations with high polyphosphate ratios.[1]

TABLE 10—Results of Calculation of Skin Temperatures Based on Temperature Coefficient of Corrosion Rate

Test No.	TEMPERATURE (°F)	
	Ucon	Calculated Skin Temp.
	380	250
B—124	365	215
B—125	385	256
B—126	390	274
B—130	370	243

Table 9 and Figure 11 show the results of some tests with zinc chromate combinations.. In these tests no phosphates were present. This type of treatment shows low scale deposition, even at a pH of 8.0 (compare specimen 212 with specimen 234 in Figure 8). There is some tendency for local attack at these temperatures and dosage levels.

Summary and Conclusions

It has been shown that it is possible to make laboratory studies of corrosion and scale deposition in heat exchange equipment under conditions of high process side temperatures.

The hairpin type specimens are better adapted to corrosion measurements, and the results obtained by their use make it possible to estimate apparent skin temperatures at the corroding surface. The approximate calculation of these skin temperatures indicates that they may be above the boiling point of water. Under such conditions, the corrosion of steel is greatly accelerated, and corrosion rates may be found up to 8 times those encountered under more normal conditions. It is suggested that further work on the effect of high process side temperatures carried out in equipment of this type may supply data that will be helpful in the design of heat exchange equipment.

The tube type specimens are too large for corrosion weight loss measurements and are most useful for the study of scale deposition. Results of tests using this equipment show the effect of chromates in reducing the amount of scale deposited by polyphosphates under high skin temperature conditions.

It is felt that further work with specimens such as these is needed in order to explain and confirm some of the results already obtained, and to improve the method of test so that the results will be more reproducible. Studies are planned with other metals, with other types of water, and with other temperature ranges. The results reported here are from the laboratory and are only partially confirmed by pilot scale and field data. Accordingly, the conclusions should be considered tentative.

Acknowledgment

The author wishes to acknowledge the help of the following Dearborn personnel who have encouraged him in one way or another in this work: J. F. Wilkes, W. L. Denman and R. G. Dalbke.

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DISCUSSION

Question by John R. Boyd, James B. Clow and Sons, Inc., Coshocton, Ohio:

We are wondering if your methods of corrosion and scale deposition determination can be used by us. We make 18 ft. long cast iron pipe in a spinning metal (low alloy forged steel) mold with 1¼" wall thickness. The inside is sprayed lightly with a silica based ceramic spray. Then molten iron at about 2300-2400 F is evenly distributed the length of the mold. The spinning mold is cooled with treated water circulating to and from a cooling pond. If your method is not applicable here, what method do you suggest (chromate-polyphosphate is method of treatment).

Reply by Herman Kerst:

Your problem is of an entirely different order of magnitude from the one considered in our investigation. Obviously it would be extremely difficult to set up a test procedure in which molten iron is pumped through a specimen, and therefore our method of studying corrosion and scale deposition is not applicable to your problem. As a matter of fact it is difficult to visualize any easily available source of heat other than a Carborundum Globar which could produce a high enough temperature to simulate the conditions of your operations. Possibly the closest approach to such studies would be some method of attaching a specimen to the water side of the metal mold. This of course is based on the assumption that it is possible to reach this part of the system in order to fasten such specimens, and that this can be done without seriously weakening the walls of the mold.

Any discussion of this article not published above will appear in June, 1961 issue.

A Contribution to the Explanation Of Intergranular Corrosion of Chromium-Nickel Steel*

By V. CIHAL(1) and M. PRAZAK(2)

Introduction

THE TENDENCY of metals and alloys toward intergranular corrosion is influenced by both the physicochemical state and structure of the alloy, and the composition and concentration of the corrosive medium. The condition of the alloy includes its fabrication history, heat-treatment, and other factors which may cause the formation of new phases and internal structural stresses.

Austenitic chromium-nickel steels of the 18-8 type are subject under certain conditions to intergranular corrosion which detrimentally affects their mechanical properties.

Today, there are several theories which explain the intergranular corrosion of these steels after heat-treatment or slow cooling in the temperature region of 450 to 850 C. According to the theory, a high-chromium phase precipitates at the grain boundaries. Very close to this phase, the amount of chromium in solid solution decreases and, consequently, its passivation tendency also decreases. The loss of corrosion resistance at the grain boundaries may also be due to local internal stresses caused by precipitation of the new phase.[1] According to some authors, this phase, separating on the grain boundaries is in itself sensitive to corrosion. According to the results of our work,[3] it appears that 18-8 stainless steels are most likely to corrode according to the theory which explains the intercrystalline corrosion by the reduction of chromium content in solid solution near the grain boundary.

Theoretical Part

The intergranular corrosion susceptibility of austenitic 18-8 stainless steels is very closely connected with the precipitation of chromium carbide in the temperature region of 450 to 850 C. Carbides precipitate from a supersaturated solid solution of carbon in austenite, mainly at the grain boundaries. Sensitivity of this steel to intercrystalline corrosion is dependent, therefore, on the amount of carbon in the solid solution. Both experimentally and theoretically it has been found that in steels with a balanced composition (18-8), the chrome carbides of the Type $Cr_{23}C_6$ are precipitated.[2, 3] Because the diffusion rate of chromium in austenite is considerably lower than the diffusion rate of carbon,

Abstract

Intercrystalline corrosion in chromium-nickel steels is considered from both a theoretical and practical standpoint. Laboratory tests were conducted to determine the effect on Invar alloy and 18 chromium-9 nickel alloy of boiling sulfuric acid containing copper sulfate. Specimens subjected to various heat treatment were tested. Polarization curves and passivation potentials of alloys are given.

The use of a potentiostat proved helpful in determining intercrystalline corrosion susceptibility, especially for steels with a low carbon content and those containing stabilizing elements which demonstrate only a slight tendency to intercrystalline corrosion. The extent of intergranular corrosion depends on the amount of precipitated chromium carbide and on the redox potential of the solution. 3.2.2

the precipitation of carbide in the above-mentioned critical temperature region changes the concentration of chromium near the grain boundaries. The reduction of chromium concentration near the grain boundary, at a given carbon content, will depend both on the temperature as well as on the time of the precipitation treatment.

The reduction of chromium concentration in a solid solution with iron and nickel reduces the passivation ability of the solid solution. The passivation potentials of ferrochromium alloys shift to higher positive potentials with decreasing chromium as shown in Table 1 and Figure 1 which are constructed from our data and those in the literature. Others often differentiate between the passivation potential and activation potential; however, in general, these mean the same thing.

Let us apply electrochemical measurements on the iron-chromium alloys to the conditions near the grain boundaries of the 18-8 steel. Because the carbides which are being precipitated $(CrFe)_{23}C_6$ can take as much as 30 atomic percent of iron into solid solution, not only will the chrome content drop close to the carbide particles, but at the same time the nickel content will rise above the original 8-9 percent which is present in the alloy. According to the amount of precipitated carbide, the intercrystalline material can be considered to be a nickel alloy with a variable chromium content. With the variation of chromium content adjacent to the grain boundary, the passivation potential should change also from the passivation value of 18-8 steel to, in the limiting case, the passivation potential of iron-nickel alloy. This increasing passivation potential decreases the passivating tendency of the grain boundaries. Under these conditions, the grain boundaries with a low chromium content could stay in an active state and corrode while the remaining part of the austenitic grain is passive and, therefore, resistant to corrosion.

TABLE 1—Passivation Potentials (E_H) of Iron-Chromium Alloys in Solutions at ph = 0 and 20C

Carbonyl Iron	+690 mv.
Fe (according to Franek)	+560
Fe-26 Ni*	+510
Fe*	+500
Fe-2.2% Cr	+670
Fe-4.4% Cr	+660
Fe-7.5% Cr	+590
Fe-9.2% Cr	+500
Fe-11.6% Cr	+280
Fe-14.2% Cr	+70
18-9* stainless steel	+50 to +100
Fe-19.1% Cr	— 20
Fe-24.4% Cr	— 80
Cr	—220
Cr (according to Mueller & Cupr)	—240
Cr*	—250

* According to our measurements in normal H_2SO_4

Experimental Part

In order to verify the theoretical assumptions, we chose two alloys, an 18 chromium-9 nickel alloy and a ferronickel alloy (Invar). The chemical compositions are given in Table 2. The 18-9 steel was heat-treated for one hour at 1250 C and quenched in water, followed by sensitizing heat-treatments at 650 C for 30 minutes, 4 hours, and 72 hours. By these heat-treatments, we obtained samples of 18-9 steel with various amounts of precipitated carbides at the grain boundaries with a varying tendency to intercrystalline corrosion. The susceptibility to intercrystalline corrosion was checked by 100-hour corrosion tests in a boiling solution of H_2SO_4 with copper sulfate (100 grams of concentrated H_2SO_4 plus 100 grams of $CuSO_4 \cdot 5H_2O$ diluted to one liter with water). The results of bend tests after exposure to this medium are shown in Figure 2*. The specimen which was solution-quenched (No. 1) and the one

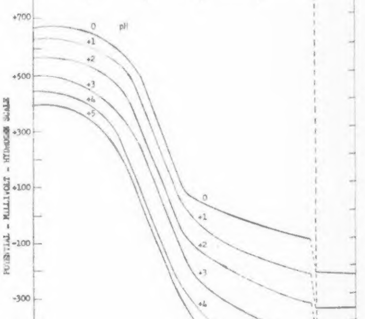

Figure 1—Dependence of passivation potential of ferrochromium alloys in H_2SO_4 at 20 C as a function of chromium content and pH (Taken from Reference 4).

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* Not reproduced in this translation.

★ English translation by F. R. Charvat, Metals Research Laboratories, Union Carbide Metals Co., Division of Union Carbide Corp., Niagara Falls, N. Y. This paper originally appeared in *Hutnické Listy*, 11, No. 4, 225 (1956). The translated version was submitted for publication on March 28, 1960.

(1) Chief metallurgist in the Materials Section of the State's Research Institute for Materials Protection, Prague, Czechoslovakia.

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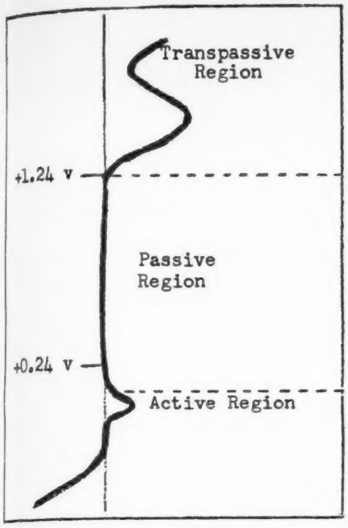

Figure 3—Polarization curve of 18-9 stainless steel, water-quenched after 1 hour at 1250 C.

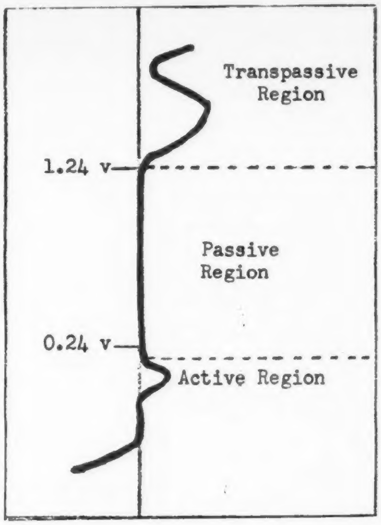

Figure 4—Polarization curve of 18-9 stainless steel, water-quenched after 1 hour at 1250 C and then heated for 72 hours at 650 C.

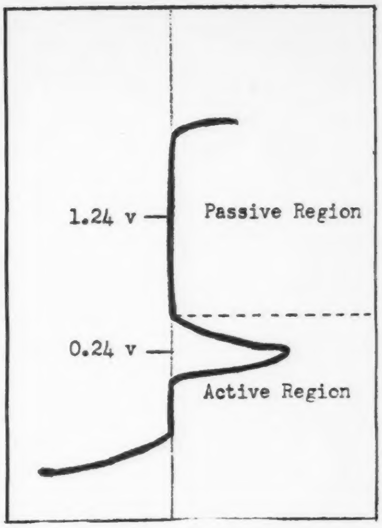

Figure 5—polarization curve of Iron-36 nickel alloy.

TABLE 2—Composition of 18-9 Stainless Steel and Ferronickel Alloy (Invar)

	Percent							
Alloy	C	Mn	Si	Cr	Ni	Mo	P	S
18-9	0.05	1.5	0.62	18.48	9.34	....	....	....
Invar	0.08	0.36	0.16	....	35.22	0.01	0.014	0.014

which was sensitized for 30 minutes (No. 2) were not affected by intergranular corrosion. Specimen No. 3, sensitized for 4 hours, shows a slight tendency to intercrystalline corrosion, while Specimen No. 4 demonstrates more extensive intergranular attack. The extent of intercrystalline corrosion is small because of the low carbon content and would disappear entirely if lower sensitizing temperatures were used.

By an electronic instrument called a potentiostat,[5] it is possible to measure polarization curves of an electrode by continuously varying its potential. The potentiostatic polarization curves of the solution-quenched 18-9 steel and the iron-36 nickel alloy are shown in Figures 3 and 5. Polarization curves were measured with 1 cm.^{2} electrodes in normal sulfuric acid at 20 C.** All potentials shown in this work are relative to the standard hydrogen electrode (E_H).

Sensitizing heat-treatment has only a small influence on the shape of the polarization curve, as shown in Figure 4, which is the curve taken from a specimen of 18-9, heat-treated 72 hours at 650 C. This is caused by the fact that the grain boundaries represent only a very small part of the total electrode surface, and thus the shape of the polarization curve depends primarily on the composition of the alloy. Indicated on the polarization curves are three important potential areas: active, passive, and transpassive. Corrosion rates are high in the active and transpassive regions, and low in the central passive area. Active stainless steel transforms to the passive state at the passivation potential of +100 mv. At +1.2 volts, the steel changes from the passive state to the transpassive state. The increase in dissolution rate in this region is typical of chrome alloys because chromium oxidizes easily at these high potentials. Corrosion products are primarily hexavalent ions of chromium.

To further study the intercrystalline corrosion of 18-9 steel, the polarization curve of the iron-36 nickel alloy is interesting. The active area of this chromium-free alloy occurs at a more positive potential (Figure 5). The passivation potential of iron-nickel alloys is only slightly dependent on nickel content as shown by experiments on pure iron and alloys with 20, 36, and 42 percent nickel. The passivation potential of iron-36 nickel was approximately +510 mv. This alloy has no transpassive region. Therefore, if the solid solution near the grain boundary contains only iron and nickel in the limiting case, it will only passivate at potentials above +510 mv.

For a more accurate check on the passivation potential of grain boundaries, we have tested metallographically polished sections of variously heat-treated 18-9 steel by electrolytic etching in normal H_2SO_4. Samples with an area of one square centimeter were electrolytically etched for three minutes at constant potential with a potentiostat. Results of tese tests at +600, +300, +100, +50, and 0 mv are shown in Table 3. A potential of +600 mv lies above the passivation potential of the iron-nickel alloy so that in no case was there any etching of the grain boundaries in a normal sulfuric acid. Only at a potential of +300 mv did the grain boundaries begin to etch in samples which were sensitized for 72 hours at 650 C. The amount of precipitated carbides is sufficient to cause intercrystalline corrosion. The etching of the grain boundaries increases as the potential becomes more negative. The amount of carbide precipitated after a 4-hour heat-treatment changes the composition of the matrix near grain boundaries so slightly that at +300 mv one still cannot see any preferential etching even after a relatively long etching time. Such boundaries only etch at +100 mv and become even more prominent at lower potentials.

Samples heat-treated for only 30 minutes at 650 C begin to etch at the grain boundaries only if the potential is ±0 mv. This potential is close to the change from the passive to active states for 18-9 steel (Figure 3). From the interrupted character of etched grain boundaries, it is obvious that only a very small amount of carbide was precipitated which changed only slightly the composition of the adjacent solid solution. This result agrees with the above-mentioned standard test for intercrystalline corrosion. Samples of the alloy heat-treated for one hour at 1250 C and water-quenched were not etched at grain boundaries.

From the above results it follows that the precipitation of chromium carbide on the grain boundaries of austenitic steels actually causes changes in the composition of the adjacent solid solution in near surrounding area. The material near the grain boundary becomes depleted of chromium and its passivation potential is shifted to more positive values, finally approaching that of ferronickel and iron. The grain boundaries with the lowest chromium content are, therefore, capable of passivation only at potentials

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** Authors' Addition: The method described here has been recently modified by the addition of NH_4CNS or KCNS to the acid and by a more precise determination of the optimum etching potential (see: *Werkstoffe und Korrosion*, 9, 517-519 (1958) and *Collection Czechoslav. Chem. Commun.*, 24, 9-15 (1959).

TABLE 3—Summary of the Etching of Austenitic Grain Boundaries of 18-8 Steel Samples Which Vary in Their Intercrystalline Corrosion Resistance at Given Potentials. Samples Were Held in 1 N Sulfuric Acid at the Given Potential Using a Potentiostat for Three Minutes. Magnification 150X.

Potential in Solution in Millivolts	HEAT TREATMENT		
	1250C for 1 hour and quenched in water + 650C for from 30 minutes to 72 hours and cooled in air.		
	30 Minutes	4 Hours	72 Hours
+600	Potential lies above the passivation potential of iron and Fe-Ni alloy		(Photomicrograph shows slight pitting)
+300	Grain boundaries still do not etch	(Photomicrograph shows slight pitting)	(Photomicrograph shows slight pitting)
+100	(Photomicrograph shows pitting)	(Photomicrograph shows pitting)	(Photomicrograph shows pitting and slight grain boundary etching)
+50	(Photomicrograph shows pitting)	(Photomicrograph shows pitting and slight grain boundary etching)	(Photomicrograph shows pitting and heavy grain boundary etching)
±0	(Photomicrograph shows pitting and slight grain boundary etching)	(Photomicrograph shows pitting and heavy grain boundary etching)	(Photomicrograph shows pitting and heavy grain boundary etching)

above +510 mv.*** Etching at low potentials, one can see pit corrosion. Its main cause is probably the deformation during the mechanical cutting of the specimen. Thus, deformation could not be removed by electrolytic polishing without intergranular attack.

Discussion of the Results

If we compare the electrochemical observations with the intergranular corrosion susceptibility observed during standard tests, we will see that the extent of corrosion increases with the length of heat-treatment. Standard tests, because of the electrochemical behavior of the H_2SO_4-$CuSO_4$ solution, will not detect intergranular corrosion susceptibility if the passivation potential of the grain boundaries in normal H_2SO_4 lies below 100 mv at room temperature. In boiling 10-15 percent sulfuric acid the passive state of 18-8 steel lies between +0.3 to 0.9 volt.[6] The redox potential of a copper sulfate solution varies around +0.75 volt. During the corrosion reaction, Cu^{+2} will be reduced to Cu^{+} so that the ratio Cu^{+2}/Cu^{+} is reduced, and the oxidation reduction potential will drop to +350 to +450 mv (Figure 6). However, this potential is reached only after a long boiling time and only in samples quite sensitive to intercrystalline corrosion. In order to determine intercrystalline corrosion of steels which are only slightly sensitive, several samples with a great tendency to corrosion should be tested simultaneously (this is how we conducted our tests). It can be seen that the standard H_2SO_4-$CuSO_4$ tests which state that only one sample should be tested in a container is not well defined, especially for stabilized steels and those which are not very sensitive to intercrystalline corrosion. These latter cases are really technically more important. The tests, as stated, do not precisely indicate intergranular corrosion susceptibility. However, if very many specimens which are susceptible to intergranular corrosion are tested in the same container, the iron present in the solution will tend to prevent the fall of the redox potential.

The redox potential will never drop below +350 mv because copper would precipitate and hold the potential at this point. This fact was used by Brauns and Pier[7] who added metallic copper to the standard solution so that its redox potential immediately fell from +0.7 to +0.5 volt, followed by a slow fall to approximately +0.350 volt, by the reaction: $Cu + Cu^{+2} \rightarrow 2\ Cu^{+}$. Metallic copper also reduced Fe^{+3} to Fe^{+2}. Metallic copper in contact with samples of steel is also good because from the beginning to the end of the test the potentials of the samples are constant. With less sensitive samples, therefore, there will not be any time delay before intergranular attack begins. Also, iron resulting from the intercrystalline attack will not be bothersome and, hence, numerous samples may be tested in the same container.

Intercrystalline corrosion will occur in the presence of copper in a standard solution with the greatest possible speed. Because the solution contains a large amount of depolarizer (Cu_{2+}) and the steel is in contact with the metallic copper, the passivity of the grains will be maintained by this simple potentiostat. The time of test can also be reduced to 15-48 hours. In order to check the performance of this simple polarization setup, we tested samples similar to those previously mentioned for 100 hours in a boiling solution containing copper filings. The results of the tests were identical to those tests performed without copper filings, but the intercrystalline attack was considerably higher, proving that the solution will start to be effective from the very beginning of the test provided metallic copper is present. If we compare the results of standard tests with the potentiostatic etching tests in normal sulfuric acid, we see that the standard test does not detect the very small intergranular corrosion susceptibility of samples heat-treated for only 30 minutes at 650 C.

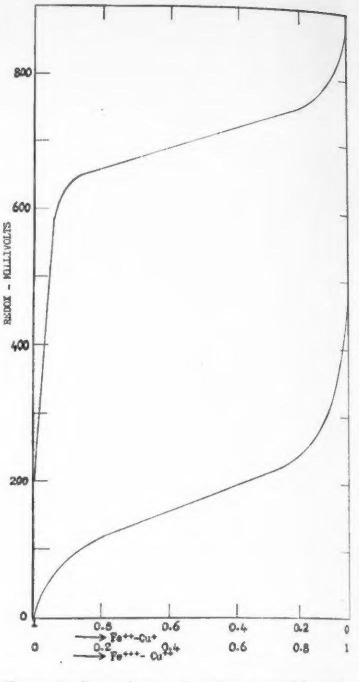

Figure 6—Dependence of redox potential on the ratios CU^{+}/Cu^{+2} and Fe^{+2}/Fe^{+3} (Nernst-Peters).

In this case, the passivation potential of the grain boundaries in normal H_2SO_4 at room temperature is below 100 mv and in a standard boiling solution under +350 mv, so that this solution has no effect whatsoever on the sample.

Conclusion

In this work, we have clarified the theoretical basis for intercrystalline corrosion in chromium-nickel steels. We have also employed potentiostatic procedures for maintaining constant electrode potentials in an electrolyte. This technique is very useful for determining intercrystalline corrosion susceptibility, especially for steels with a low carbon content and those containing stabilizing elements which demonstrate only a slight tendency to intercrystalline corrosion and, hence, cannot be tested by conventional procedures. The extent of intergranular corrosion depends on the amount of precipitated chromium carbide and on the redox potential of the solution. Reduction of the chromium content adjacent to the carbide will change the passivation potential of the grain boundary; moving it in the noble direction. In the limiting case, the passivation potential of the grain boundary approaches the value of the passivation potential of a ferronickel alloy.

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*** Authors' Addition: During later work we observed that intergranular corrosion can occur at potentials above the passivation potential of grain boundaries. In this case, we believe another mechanism causes the greater relative corrosion rate of boundaries depleted of chromium. Iron-chromium alloys show an increasing corrosion rate in the passive state as chromium content is decreased, especially below approximately 9.5 percent Cr. This factor is important during corrosion in boiling, strongly acid media (see H. H. Uhlig Corrosion Handbook—concentrated HNO_3). By the above mechanism, the detection of intergranular corrosion susceptibility by boiling concentrated nitric acid can be explained. In this case, corrosion occurs predominantly in the passive state with only a small amount of the total corrosion being of transpassive character.

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T-4G Protection of Pipe Type Cables

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T-4J-1 Interference from Cathodic Protection Rectifiers

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T-5C Corrosion by Cooling Waters

T-5C-1 Corrosion by Cooling Waters (South Central Region)

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T-6A-20 Plastisols

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T-6H-2 Porcelain Enamel Coatings

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T-6J-2 Application Procedure

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T-6J-3 Inspection Techniques

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TECHNICAL ARTICLES SCHEDULED FOR PUBLICATION

November Issue

Corrosion of Tube Materials by Boiler Sludge, by E. Howells, T. A. McNary and D. E. White

Corrosion Problems in the Use of Salt Solutions as Packer Fluids, by C. M. Hudgins, W. D. Greathouse and J. E. Landers

Some Factors Governing Corrosion Testing of Zircaloy Base Fuel Alloys, by Stanley Kass and R. F. Gessner

Selective Corrosion of Inconel, by F. Kern and R. Bakish

Stress Corrosion Cracking of High Strength Tubular Goods, by R. S. Ladley

Stress Corrosion Cracking in Concentrated Sodium Nitrate Solutions, by R. L. McGlasson, W. D. Greathouse and C. M. Hudgins

High Temperature Furnace Corrosion, by R. D. Merrick

Cracking of Low Carbon Steel by Ferric Chloride Solutions, by Mary Boehm Strauss and M. C. Bloom

Things New or Unusual in Mitigation of Corrosion in the Utilities Field, by E. H. Thalmann

Metals for Combatting Corrosion in the Process Industry, by F. L. Whitney, Jr.

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Effect of Various Curing Agents on Chemical Resistance of Epoxy Resins, by Ronald L. DeHoff

Internal Carburization and Oxidation of Nickel-Chromium Alloys in Carbon Monoxide, by B. E. Hopkinson and H. R. Copson

Ship Coating of Structural Steel, by John D. Keane

Impressed Current Anodes for Cathodic Protection, by Walter P. Noser

High Temperature Corrosion in Refinery and Petrochemical Service, by E. N. Skinner, J. F. Mason and J. J. Moran

Inhibition of the Corrosion of Commercial Aluminum Alkaline Solutions, by J. Sundarajan and T. L. Rama Char

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Effect of Sodium Exposure on Mechanical Properties of Zirconium, by Jack C. Bokros

Accelerated Test Procedure for Evaluation of Fiber Reinforced Resin Equipment in the Chemical Industry, by Robert A. Cass and Otto H. Fenner Corrosion Studies of Aluminum in Chemical Process Operation, by E. H. Cook, R. L. Horst and W. W. Binger

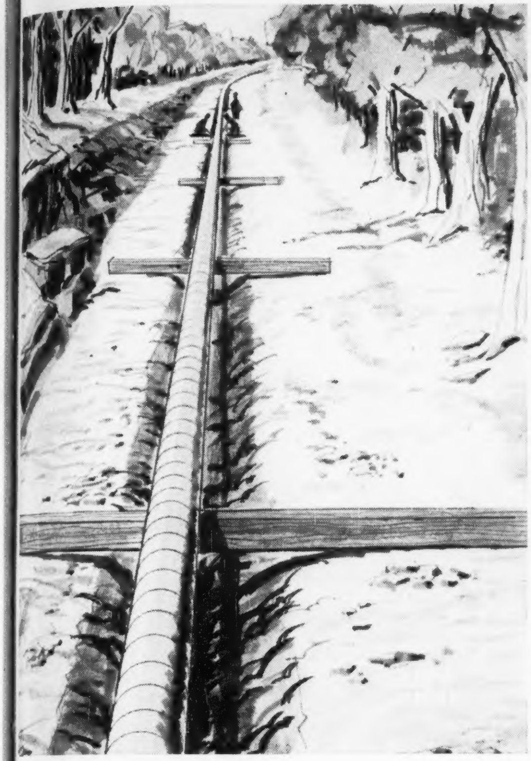
Corrosion Resistance of Dense, Impermeable Silicon Carbide, by Roy Dial and G. E. Mangsen

Design for Prevention of Pipe Corrosion Based on Survey of Ground Potential Distribution of the Planned Route, by Shigeo Fukata

Characteristics of Asphalt Mastic Coatings, by Lyle R. Sheppard

Corrosion-Erosion of Sensitized AISI Type 304 Stainless Steel in a Thorium Dioxide-Uranium Trioxide Slurry, by Donald C. Vreeland

Symposium on Methods and Experiences in Underground Cathodic Protection
(1) Methods and Experiences of the Ohio Bell Telephone Company in Cleveland with Cathodic Protection of Underground Cables, by Oliver Henderson
(2) Methods and Experiences in Underground Protection, by P. P. Skule
(3) Methods and Experiences in Underground Cathodic Protection, by L. H. West



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D	2" x 60"	2.6	46	Ground Bed
E	3" x 60"	4.0	115	Salt Water
G	2" x 9"	0.4	5	Ducts
J	3" x 36"	2.5	80	Salt Water
M	2" x 60"	2.8	57	Salt Water

*Applicable also in fresh water service. Should not be used in ground beds without backfill.

THE DURIRON COMPANY, INC.
DAYTON, OHIO

DURCO
CORROSION RESISTING ALLOYS & EQUIPMENT

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